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TEXTILE RESEARCH JOURNAL

Synthesis and Structure of Fiber Forming Polymethylene Sulfones and Evaluation of Such a Polysulfone Fiber[1]

H. D. Noether

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Introduction

Linear high molecular weight hydrocarbons such as polymethylene or the linear types of polyethylene can be considered the parent polymers from which many other organic polymers can be derived on regular substitution of methylene groups by other atoms or atomic groups such as oxygen, sulfur, carbonyl, ester, and amide. The characteristics of such polymers depend on the nature of the substituting groups and on the frequency with which this substitution occurs in the basic polymethylene chain. It is known, for example, that the substitution of oxygen, sulfur, or carboxyl groups for a CH_2 group in polymethylene in general lowers the melting point compared to that of polymethylene, while the introduction of urethane, amide, or urea groups increases the melting point. A comparison of low molecular weight structures containing the latter groups with equivalent sulfones shows that the sulfones have melting points in the same temperature range. Therefore, polysulfones of comparable polymer structure also should provide high melting useful products.

Fiber forming materials with desirable properties should have a high temperature resistance. This can be achieved by building polymers of regular symmetrical structure to permit easy crystallization and by introducing polar groups or comparatively stiff atomic groups to allow the retention of the crystalline structure at adequately high temperature.

Synthesis and Properties of Polysulfones[2]

Several syntheses of polysulfones are possible depending on the type of structure desired. A polymer where each third methylene group has been replaced by a sulfone group is available by the polymerization of ethylene and sulfur dioxide. This ethylene polysulfone and others prepared by reaction of SO_2 with olefins are highly alkali sensitive; up to the present, desirable polymers for plastic or fiber applications have not been obtained due to this instability to alkali and due to their rate of decomposition in the melting or softening range [6].

Polymethylene sulfones containing more than two

[1] Presented at the Fall Meeting of The Fiber Society, New York City, September 7, 1956.

[2] The notation used in this paper for the polysulfides and polysulfones is a shorthand where P stands for "poly," the numbers for the length of the polymethylene units between the sulfide or sulfone groups and S or SO_2 for sulfide or sulfone, resp. For example $P_{4,5}S$ stands for polytetramethylene pentamethylene sulfide and $P_{4,5}SO_2$ for the corresponding polysulfone.

TABLE I. Structure and Synthesis of Polymethylene Sulfones

$$-SO_2(CH_2)_xSO_2(CH_2)_y- \qquad x = 4, 5, 6 \cdots \qquad y = 4, 5, 6 \cdots$$

$$n\ NaS(CH_2)_6SNa + n\ Br(CH_2)_5Br \rightarrow -S(CH_2)_6S(CH_2)_5- + 2n\ NaBr$$

$$-S(CH_2)_6S(CH_2)_5- + 4n\ H_2O_2 \rightarrow -SO_2(CH_2)_6SO_2(CH_2)_5- + 4n\ H_2O$$

TABLE II. Refractive Indices (n_D^{25}) of Methylene Dibromides and Dimercaptans

	Dibromide	Dimercaptan
$-(CH_2)_4-$	1.5169	1.5270
$-(CH_2)_5-$	1,5105	1.5200
$-(CH_2)_6-$	1.5050	1.5110

TABLE III. Intrinsic Viscosities of Polysulfides and Melting Points of the Corresponding Polysulfones

Type of polysulfide	I.V.* of polysulfide	Type of polysulfone	M.P., °C., of polysulfone
P_4S	.82	P_4SO_2	271 or higher
$P_{4,5}S$	.80	$P_{4,5}SO_2$	246–7
$P_{4,6}S$	.67	$P_{4,6}SO_2$	243–6
P_5S	.73	P_5SO_2	243
$P_{5,6}S$	.72	$P_{5,6}SO_2$	223
P_6S	1.02	P_6SO_2†	220

* I.V. = inherent viscosity $(\ln \eta_r/c)c = 0.1\%$, where η_r, the relative viscosity, is η/η_0, η being the visocisty of the solution, and η_0 that of the pure solvent, here *m*-cresol.

† The inherent viscosity of this sulfone is 1.14. All the other sulfones are insoluble in *m*-cresol.

carbon atoms between the sulfone groups cannot be synthesized by this means. Table I shows their structure and one method for their synthesis. Very pure dimercaptans are converted to mercaptides and condensed with dihalides to give high molecular weight polysulfides. A choice of structures can be made depending on the number of methylene groups in the dihalide and dimercaptan.[3] Emphasis must be placed on the purity of the starting materials and equivalence of halide and mercaptan to obtain high molecular weights. Table II gives the refractive indices of the various dibromides and dimercaptans used in this synthesis. Dimercaptans are not very desirable materials to work with; the low boiling ones (i.e., tri-, tetra-, penta-methylene dimercaptans) have a very strong and retentive odor; the high boiling ones (hexamethylene dithiol and those of higher molecular weight) can cause severe dermatitic effects.

[3] As indicated in Table I, the sodium dimercaptide, prepared by adding metallic sodium to the solution of the dimercaptan in ethanol, was condensed with a dibromide at the reflux temperature of the alcohol.

Neither the polymethylene sulfides nor the polymethylene sulfones are soluble in a satisfactory oxidizing medium. Therefore, a satisfactory method of oxidation to the polysulfones in a heterogeneous system had to be developed. A reaction medium of 60% or higher concentration of formic acid proved very useful, 90% H_2O_2 being added at such a rate to hold the reaction at the desirable temperature [3]. Only at the intermediate sulfoxide stage does the polymer go into solution. The oxidation procedure has to be as quantitative as possible to avoid residual sulfoxides, which lead to thermally unstable compounds.

Table III indicates some of the type of polysulfones which were prepared, the intrinsic viscosities of the polysulfides and sulfones, and the melting points of the latter. The first two columns indicate the number of methylene groups between the sulfone groups; the last column lists the melting points of these polysulfones. They are quite high, ranging from 220–271°C. Figure 1 shows x-ray diffraction patterns of polyhexamethylene sulfone in powder form and as a drawn fiber, and also the pattern of powder and undrawn polypentamethylene sulfone. Figure 2 shows the diagrams of the other polysulfones in powder form or as meltspun fibers, while Figure 3 shows these same fibers after drawing. All have high crystallinity (fiber-to-film distance 35 mm.).

Structure of Polysulfones

A partial structural evaluation of the x-ray diffraction pattern yields the following results. The lateral dimensions of all the unit cells are identical for the polysulfones prepared so far. Assuming carbon–carbon distances of 1.54 Å, carbon–sulfur distances of 1.82 Å, and tetrahedral angles all along the chain, we can calculate the length of the chain unit; the results of Table IV are thus obtained and compared to measured values [4].

The fact that the proposed unit cell structure fits all these polymers and allows the assignment of all observed diffraction spots to specific and consistent diffracting planes increases the confidence in the results.

The agreement of the calculated with the observed length of the unit cell in the fiber direction indicates that the chains are fully extended or nearly so; they must be planar (or very nearly planar) zig-zag, because any considerable rotation around the bonds to give a nonplanar spiral would shorten the repeat distances. Actually, in all cases the observed distances are slightly shorter than the calculated ones, especially for the $P_{6,5}SO_2$ and $P_{4,5}SO_2$; considering that here the repeat unit contains four sulfone groups and therefore eight carbon–sulfur bonds, the bond length of which is not known too accurately, the discrepancy is not too serious.

As shown elsewhere [4], the major features of the diffraction pattern of these sulfones can be realized with a monoclinic unit cell, but considerable work still is required to calculate the arrangement of the atoms in the unit cell.

Comparison of the melting points of the polysulfones of this series with those of corresponding polyamides reveals some unexpected characteristics. There is no zig-zag relationship of melting points of the polymers on change of composition as is observed in polyamides [2], but only an increase in m.p. on shortening the carbon chain between sulfone groups. In addition, the melting points of 4, 6 and 5 polysulfones are the same.

On comparing melting points of different series of polymers, compounds with identical hydrocarbon sec-

TABLE IV. Unit Cell* Dimensions of Polysulfones from X-Ray Data [4]

Polysulfone	C, fiber axis length in Å		
	Calc.	Obs.	
P_6SO_2	18.52	18.24	a = 9.88 Å
$P_{6,5}SO_2$	34.52	34.00	b = 9.26 Å
$P_{6,4}SO_2$	16.00	15.68	β = 121.7°
P_5SO_2	8.00	7.76	
$P_{4,5}SO_2$	29.49	28.33	

* The unit cell contains four polymer chains. The calculated values are based on a C—C distance of 1.54 Å, a C—S distance of 1.82 Å, and tetrahedral angles all along the chain.

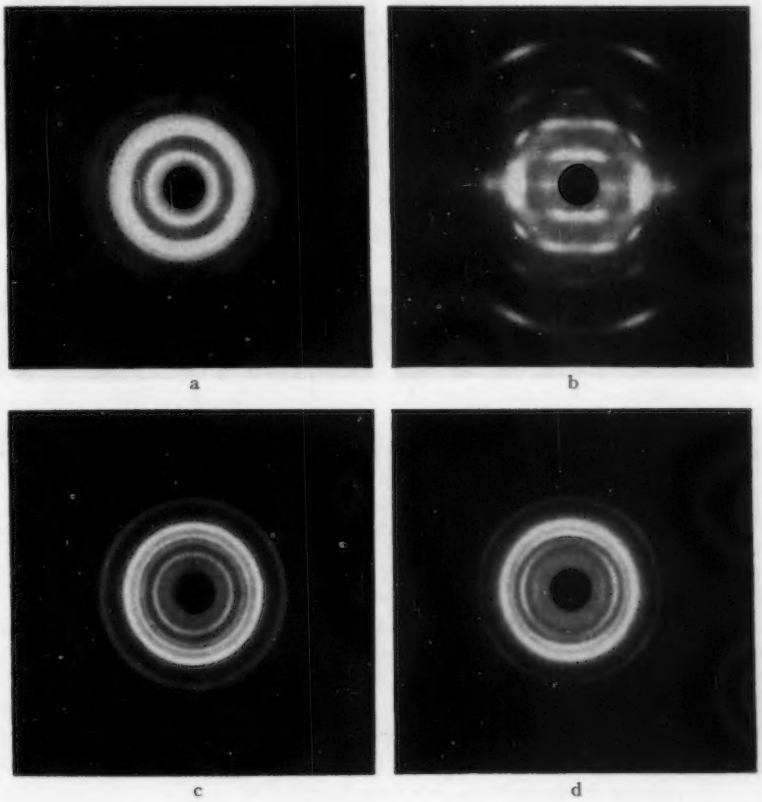

Fig. 1. X-ray diffraction patterns of polysulfones. Polyhexamethylene sulfone (a) polymer powder, (b) drawn yarn. Polypentamethylene sulfone (c) polymer powder, (d) yarn as spun.

tions should be selected. Thus, in the case of sulfones and amides, the $-SO_2-$ and $-CONH-$ groups should be considered equivalent units, placed at regular intervals in the polymethylene chain. Tables V and VI make use of this method. Here a comparison of the melting points of the even and odd sulfones with corresponding polyamides has been given. The melting points of the even polysulfones are only slightly lower than those of the corresponding polyamides, while in the odd series all the sulfones have the higher melting points.

The peculiarity of this melting point dependence of the sulfones is perhaps due to the symmetrical influence of the sulfone group on neighboring methylene groups. It is known from sulfone chemistry that this group has an effect on hydrogens at α carbons. Two sulfone groups on the same carbon make the hydrogen replaceable by alkali

TABLE V. Comparison of Melting Points of Polysulfones and Polyamides Containing Even Numbers of Methylene Groups

Polyamide Number of CH_2 groups of				Polysulfone Number of CH_2 groups of		
Diamine	Diacid	Amino acid	M.P., °C.*	$(CH_2)_x$†	$(CH_2)_y$†	M.P., °C.
4	4	—	278	4	4	271+
4	6	—	250	4	6	243
6	4	—	250–263	6	4	243
—	—	6	225	6	6	220
6	6	—	215–220	6	6	220

* Coffman et al., *J. Polymer Sci.* **2**, 306 (1947); **3**, 85 (1948).
† See Table I for x and y notation.

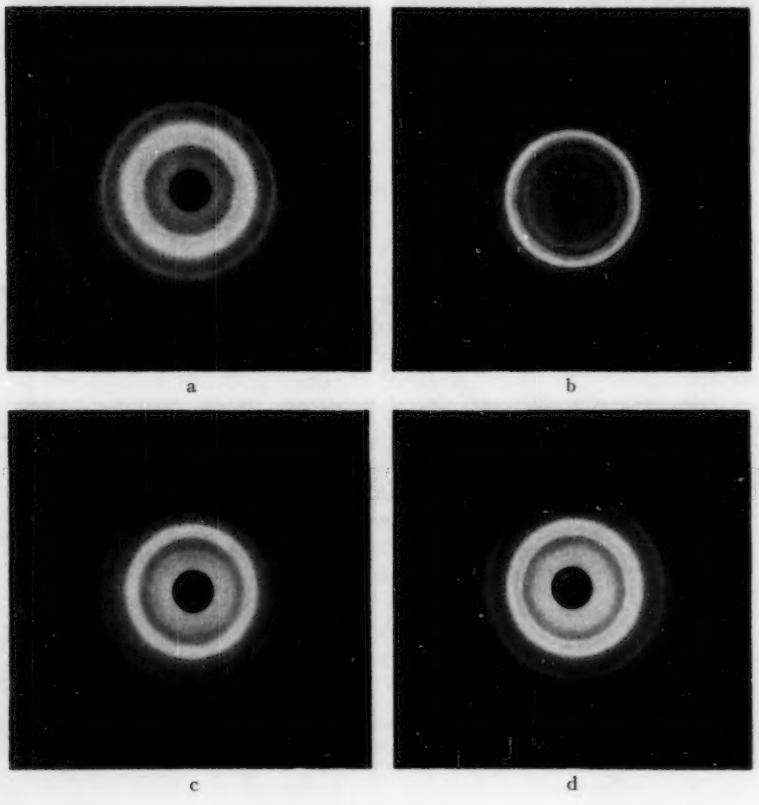

Fig. 2. X-ray diffraction patterns of polysulfones (polymer powders). (a) polytetramethylene sulfone, (b) polytetramethylene pentamethylene sulfone, (c) polytetramethylene hexamethylene sulfone, (d) polypentamethylene hexamethylene sulfone.

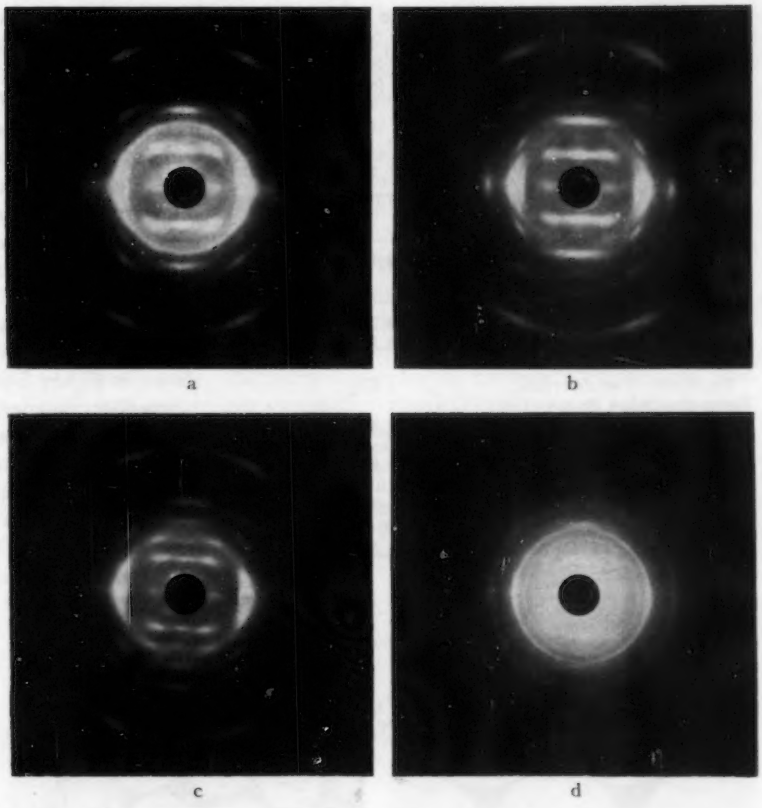

Fig. 3. X-ray diffraction patterns of drawn polysulfone fibers (fiber axis vertical). (a) polytetramethylene pentamethylene sulfone, (b) polypentamethylene hexamethylene sulfone, (c) polytetramethylene hexamethylene sulfone, (d) polypentamethylene sulfone.

TABLE VI. Comparison of Melting Points of Polysulfones and Polyamides Containing Odd Numbers of Methylene Groups

Polyamide Number of CH_2 groups of				Polysulfone Number of CH_2 groups of		
Diamine	Diacid	Amino acid	M.P., °C.*	$(CH_2)_x$†	$(CH_2)_y$†	M.P., °C.
5	4	—	223	5	4	246
5	5	—	183	5	5	243
—	—	5	205	5	5	243
5	6	—	202	5	6	223

* Coffman et al., *J. Polymer Sci.* **2**, 306 (1947); **3**, 85 (1948).
† See Table I for x and y notation.

metals. Three sulfone groups make the residual hydrogen definitely acidic [7]. Whatever the exact character of the interchain links, these links are symmetrical with respect to the sulfone group. Therefore, registration may take place with adjacent chains without consideration of the direction or shift of such chains along the fiber direction. This is not the case with the polyamides, where that type of symmetry does not exist.

With such symmetry considerations, it can be shown that the overall effect of the sulfone group for the sulfones P_4SO_2, P_5SO_2, and P_6SO_2 depends only on the frequency of occurrence of sulfone units and that the $P_{4,6}SO_2$ and P_5SO_2 polymers should be equivalent in interchain registration. Extending these considerations to other types of polysulfones should lead to a better understanding of the effects of internal symmetry on thermal properties.

Properties of a Polyhexamethylene Sulfone Fiber

One of these polysulfones, the polyhexamethylene sulfone, was converted into yarn and fabric and given a physical and chemical evaluation.

The polymer, as obtained in the oxidation procedure, was densified and then melt spun at a temperature 20–30° C. above the crystalline melting point. Yarns containing 20 and 34 filaments were spun. The yarn obtained in this manner has a slightly amber color, has a circular cross section, and shows an x-ray diffraction pattern indicating randomly oriented crystallites. This yarn can be drawn by hand or machine up to 400% at room temperature or preferably slightly above room temperature at commercial drawing and takeup rates. Figure 4 indicates cross sections of undrawn and drawn yarn and longitudinal sections of drawn yarn.

TABLE VII. Physical Properties of Polyhexamethylene Sulfone Yarn

Density	1.290
Refractive index, undrawn	1.540
Refractive index, drawn	
Parallel to fiber direction	1.578
Refractive index, drawn	
Perpendicular to fiber direction	1.516
Cross section	circular
Tenacity	2.5–3.8 g./den.
Elongation	10–18%
Wet, knot, loop tenacity	95% of dry tenacity
Initial modulus	30–40 g./den.
Moisture regain 77° F., 65% R.H.	2.2%

Table VII gives the physical and mechanical properties of drawn yarns. The moisture regain as a function of relative humidity at room temperature is shown in Figure 5 and is compared to that of nylon.

Stress–strain curves and an elastic recovery curve of this yarn are shown in Figures 6 and 7. The stress–strain characteristics change as expected with an increase in strain rate. The elastic recovery of the yarns is 95% or better at 5% elongation, but at 10% elongation the elastic contribution (immediate

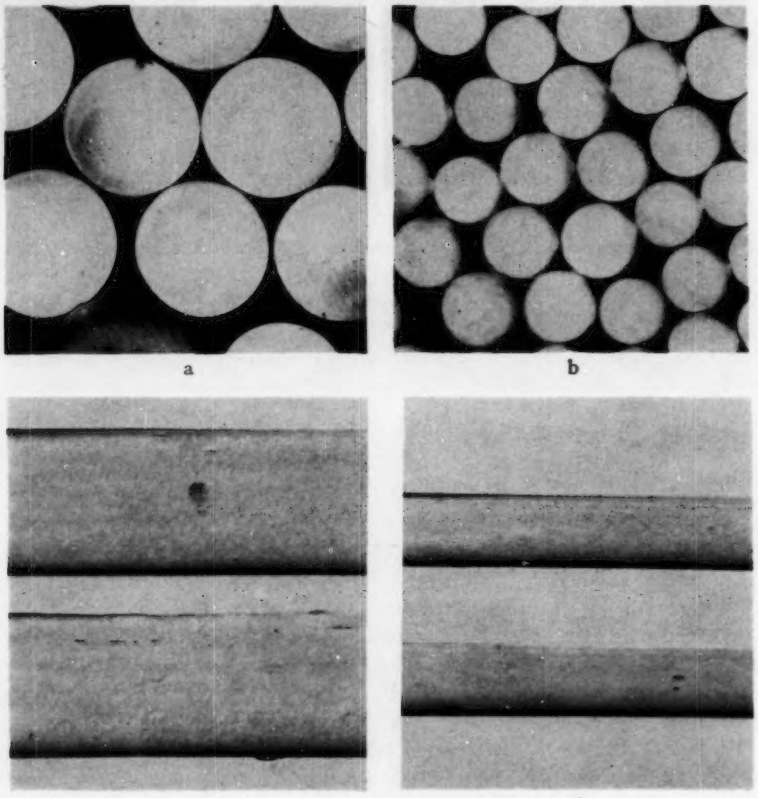

Fig. 4. Cross sections (top) and longitudinal views of polyhexamethylene sulfone yarn. Left, undrawn; right, drawn (magnification 400×).

plus delayed) drops to 70–80%. Similar results are obtained from repeated stress data.

Polyhexamethylene sulfone is insoluble in most organic and inorganic solvents. Also, since the sulfone structure of this type is insensitive to hydrolysis, considerable resistance to chemicals in general can be expected.

Figures 8 and 9 show the effect of inorganic alkalis and acids at room temperature and at 75° C., respectively, and also the action of organic drycleaning agents and other solvents.

As is evident from these figures, there is only a change to a somewhat higher elongation in the case of some acids like concentrated HCl and formic acid. The polymer dissolves in *m*-cresol only with great difficulty after it has been densified by spinning. Only concentrated sulfuric acid dissolves the polymers readily.

Textile operations such as rewinding, coning, and up or down twisting, performed with the limited amounts of yarn available, did not cause any undue difficulties. In preparing yarns for knitting, a commercial procedure for nylon was followed, rewinding and twisting up to 25 turns/in., followed by steaming to set the twist, sizing, and coning. Warping, slashing, and weaving of test ribbons and knitting of full fashion hosiery also was possible.

The fiber resembles cellulose acetate in its dyeing behavior; it dyes readily with acetate dyes and is left undyed by acid dyes. A range of anthraquinone, azo, and diphenyl-amine structures was examined, and affinity essentially equal to that of cellulose acetate was found. Washfastness for the dyes is equivalent to acetate; slight gas fading is noticeable, though the rate is significantly slower than for cellulose acetate. On the other hand, the lightfastness is slightly poorer than that of acetate. Bleaching the original slightly amber color by commercial techniques was not successful. Physical evaluation of fabric showed that the material retained the tensile properties of the parent yarn.

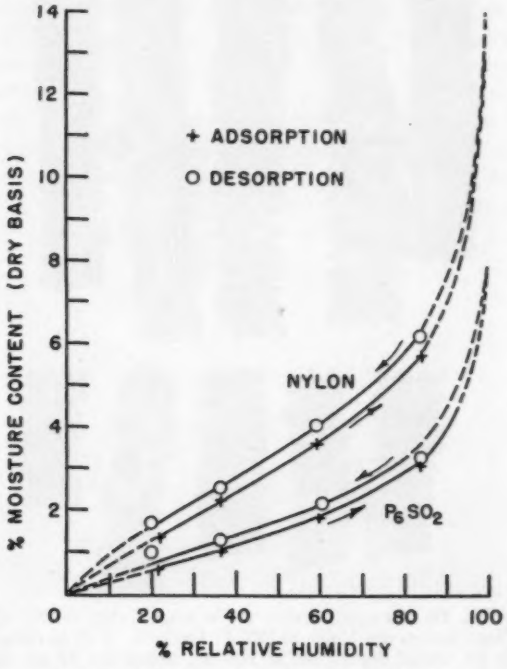

Fig. 5. Moisture regain of yarns at 25° C.

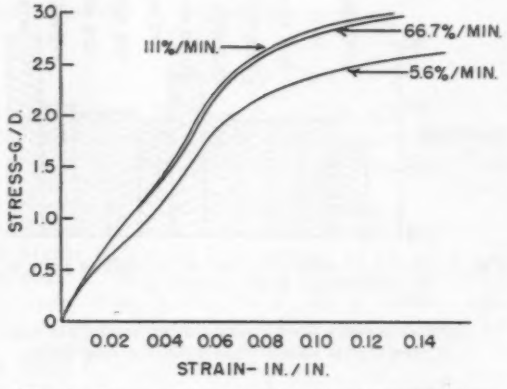

Fig. 6. Stress–strain properties of polyhexamethylene sulfone yarn.

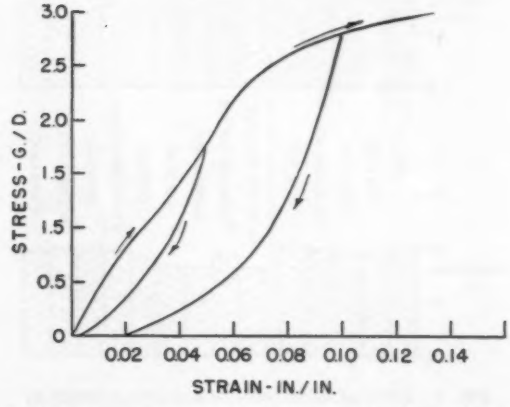

Fig. 7. Elastic recovery of polyhexamethylene sulfone yarn.

Drying time is very short, from a few minutes in a warm air oven at 70° C. for light weight materials to about 20–30 min. for heavier woven materials. The maximum safe ironing temperature for this fiber is 185° C.

The fiber can be heat set either dry or with steam at lower temperatures than nylon. Figure 10 shows the behavior of the fabrics after heat treating in various ways. Dry setting for 1 min. at 190° C. produces excellent results; the material then retains its shape during any further washing or ironing. Steam setting for 1 min. at 130–155° C. also is adequate.

Very little shrinkage (<2%) occurred on repeated steam pressing at 130° C., most of it during the first pressings. Fabric purposely wrinkled during laundering and then dried in the wrinkled state showed only small wrinkles and no sharp creases. The wrinkles can be removed again by dry ironing at 125° C.

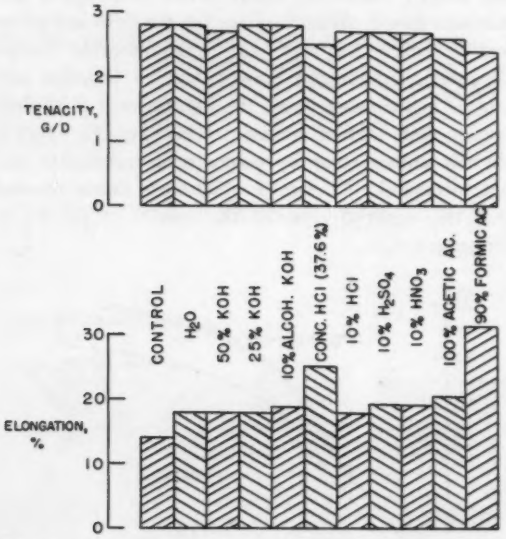

Fig. 8. Action of acids and bases on polysulfone yarn on exposure at 27° C. for ½ hr.

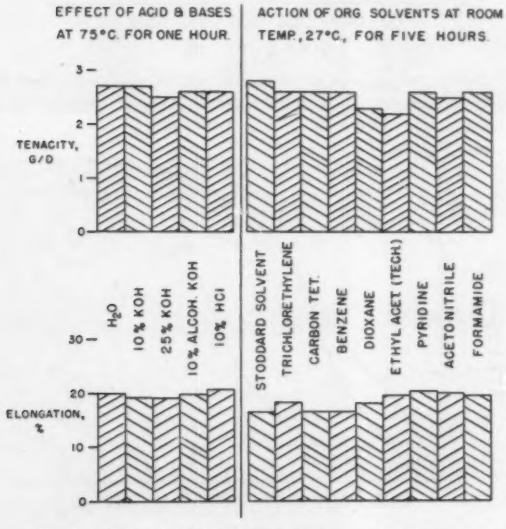

Fig. 9. Effect of acids, bases, and organic solvents on polysulfone yarn.

Summary and Conclusions

The synthesis and evaluation of fiber forming polymethylene sulfones has shown a new type of structure giving a high temperature resistance. The crystalline melting points of these polymers are very similar to those of the corresponding polyamides. The effect of change of the hydrocarbon length on melting point is different from that observed for other fiber forming polymers (amides, urethanes), since a linear behavior rather than the zig-zag pattern of m.p.

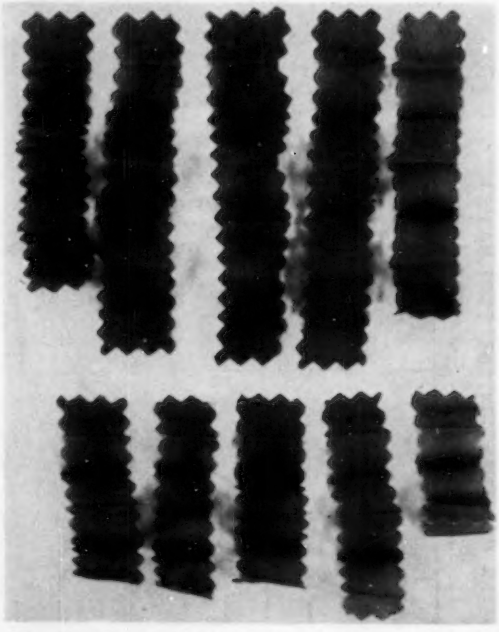

Fig. 10. Creases in fabric set in steam 1 min. at 130° C. (top) and set dry 1 min. at 190° C. (botton). Left to right: as set, ironed dry 15 sec. at 120° C., ironed dry 15 sec. at 160° C., ironed wet at 160° C., washed but not ironed.

dependence on unit length is noted. This feature may be correlatable with the symmetry of the sulfone group.

The fiber forming characteristics of the polysulfones and their crystalline character and thermal behavior are as expected of a high molecular weight linear polymer based on a linear polyethylene chain with replacements of CH_2 groups by more polar units at regular intervals.

The mechanical properties are representative of a flexible chain above its glass–rubber transition temperature. The crystallites and the interchain bonding of the sulfone groups provide creep resistant temperature dependent cross-links in the temperature range where otherwise plastic flow would occur.

Compounds having sulfone groups or a sulfone and another polar group separated by two carbon atoms are sensitive to alkali, as was shown by Stuffer [5]. Polymerization of sulfur dioxide with olefins leads to polymeric structures of this type.

The polymethylene sulfones evaluated in this paper do not have this structure and therefore show a very desirable chemical inertness towards hydrolyzing agents like acids and bases.

The relatively low moisture absorption can be surmised from the absence of hydroxyl, ether, or other highly water sensitive groups and from the considerable tendency to crystallize, in this way taking care internally of residual bonding potential. Nevertheless, enough noncrystalline regions remain and enough activity of the sulfone groups in these regions is available to provide a good dye affinity similar to that of cellulose acetate.

Adequate heat setting and annealing possibilities can be predicted on the basis of the thermoplastic behavior at high temperatures and the ease of crystallization and recrystallization in the wide temperature range below the melting point. The second order transition temperature—the glass–rubber transition—is not known at present but should be found near or somewhat below room temperature.

Difficulties in the large scale production of these types of polysulfones are primarily based on the absence of economic raw materials and on problems associated with polymer synthesis.

Acknowledgments

I want to thank my co-workers at Celanese who helped in the evaluation of the polymers, yarns, and fabrics and the Management of Celanese Corporation for permission to publish this work.

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Manuscript received December 5, 1957.

Applications of Infrared Absorption Spectroscopy to Investigations of Cotton and Modified Cottons

Part II: Chemical Modifications

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Abstract

The potassium bromide disc technique is being used for rapid, simple, and reproducible measurement of the infrared spectra of modified cotton fibers, yarns, and fabrics. Applications of the procedure have demonstrated that chemical modification can be readily detected and identified and that the extent of treatment can be quantitatively estimated. Experiments have been designed to select bands most useful in investigations of cotton modified by esterification, etherification, or replacement reactions. The examples cited illustrate the potential usefulness of infrared absorption spectra to studies in this field. A list has been prepared of 50 infrared absorption bands (and correlations with vibrating groups which give rise to them) which summarize the spectral characteristics which have been found most useful in investigations of cottons modified by esterification, etherification, and replacement reactions.

IN THE preceding paper in this series [11] applications of a recently described KBr disc technique for obtaining infrared spectra of cotton and modified cottons [12] to the investigations of physical changes in the cellulose molecule were considered. These discussions included the potential uses of infrared absorption spectra in investigations of hydrogen bonding, crystallinity, cross-linkage, and oxidation. Current investigations on chemical modification of cotton to obtain fibers and fabrics possessing specific desirable properties have opened up an entirely new area to infrared absorption: the identification of the type of modification, the quantitative measurement of the degree of modification, the elucidation of the structure of the modified cellulose molecule, or the determination of the kinetics of a modification reaction.

Details of the technique for obtaining infrared spectra of cotton by means of KBr discs have been described fully elsewhere [12]. The purpose of this paper is to discuss the present and potential applications of this technique to investigations of cottons, chemically modified to achieve specific end-use properties.

Esterification

Esterification is the most common type of reaction involved in chemically modified cotton cellulose. KBr disc spectra of a series of cottons modified by esterification with monobasic aliphatic acids are shown in Figure 1. All of these spectra are of partially esterified cottons. An esterified cotton can be recognized by the appearance, in its spectrum, of an intense band [2] at about 5.75μ, arising from a stretching vibration of the C=O group of the ester. The degree of esterification can be measured by a consideration of the intensity of this band. This is illustrated in Figure 2, the relation between the intensities of the measured absorption with increasing degree of

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[2] The wavelength position of an absorption band can be measured with an accuracy of $\pm 0.01\mu$. However, various samples of cottons modified by the same reagent at different times and to different degrees, and possibly with slight changes in modification conditions, exhibit spectra with band maxima which vary as much as $\pm 0.1\mu$. These differences in position of band maxima may represent different ratios of substitution on the different hydroxyl groups. With an instrument of higher resolution, investigations of molecules of known positions of substitution might show that these differences offer a method for the determination of the position of substitution on the cellulose molecule. In the text the wavelength positions reported are the average of the number of samples measured. Individual samples may show variations of a few hundredths of a micron.

acetylation. Percent acetyl groups were determined chemically by the Eberstadt method as modified by Genung and Mallatt [6]. With the aid of such a calibration curve the degree of esterification of any modified cotton fiber, yarn, or fabric can be obtained quickly and accurately from its infrared absorption spectrum.

In general it is not possible, by means of infrared spectra, to differentiate cottons modified by reagents which are members of the same homologous series. Several workers [8, 10] have shown that, in the crystalline state, the chain length of pure long chain, unbranched, saturated fatty acids or esters can be differentiated by means of a progression of bands in their infrared spectra between about 7 and 9μ. A careful comparison of curves A and G, Figure 1, modification by esterification with acetic and stearic acids, reveals some differences in this region. It is probable that, if only two acids of considerable difference in chain length are involved, a differentiation could be made as to which was used in a specific esterification. However, with the interference of the number of bands of the cellulose molecule in this region, it is doubtful if KBr disc spectra in the NaCl region with NaCl optics can be satisfactorily used to identify the individual members of a homologous series with which the specific sample of cotton was esterified.

In the region between about 12 and 13μ the shorter chain esters reveal bands somewhat characteristic of individual homologs. These bands, arising from C—H deformations, are seen in Figure 1 for cellulose propionate at 12.38μ, cellulose caprate at 12.88μ, and cellulose butyrate at 12.5μ. The isobutyrate can be differentiated readily from the n-butyrate by observation of the band at 7.25μ. In the spectrum of n-butyrate a single band, arising from a CH_3 (methyl) deformation, is observed. The isobutyl is a special case of "isopropyl splitting" of this band, two bands appearing whenever two methyl groups are attached to the same carbon atom. These two bands are observed in the spectrum of cellulose isobutyrate at 7.16 and 7.26μ (Figure 1F). The isobutyrate also exhibits a quite characteristic band with a maximum at 11.82μ, by means of which it could be identified and quantitatively measured.

Spectra of cottons modified by esterification with polybasic and unsaturated aliphatic acids are compared in Figure 3. Short chain symmetrical alpha-omega dicarboxylic acids can frequently be dis-

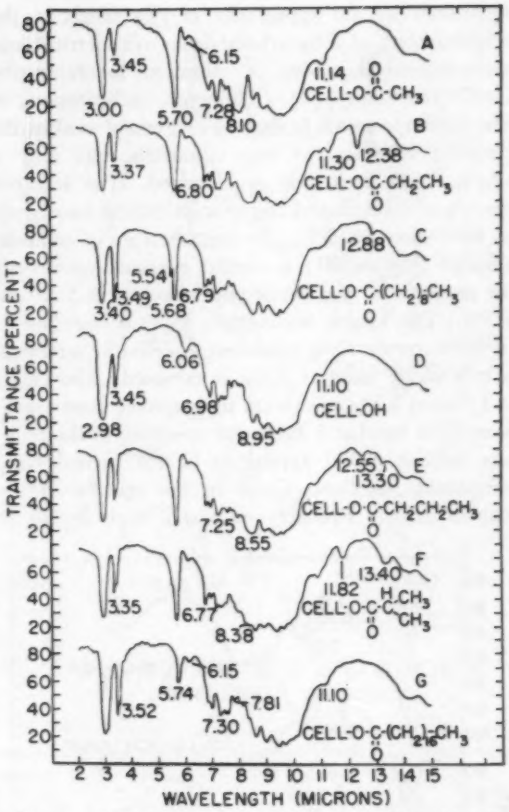

Fig. 1. Infrared spectra of cotton esterified with monobasic aliphatic acids: A, acetic; B, propionic; C, capric; E, butyric; F, isobutyric; G, stearic; and D, unmodified cotton.

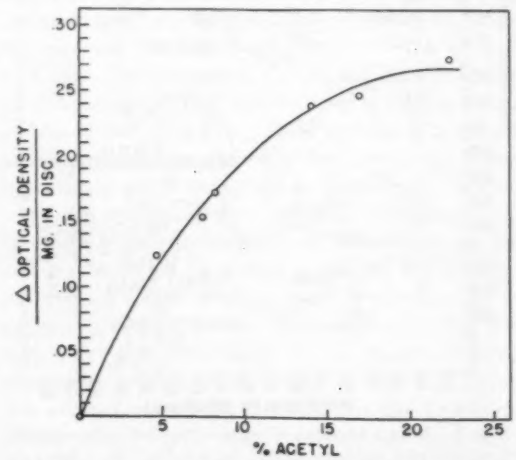

Fig. 2. Increase in intensity of 5.73 μ band with degree of acetylation.

tinguished by the appearance of two bands in the neighborhood of 5.8μ arising from symmetrical and antisymmetrical modes of vibration involving the C=O stretching [3]. However, substitution of heavy groups seems to destroy or greatly weaken the coupling between the two vibrations, and only a single C=O stretching is observed. The infrared spectra of succinic and adipic acids exhibit two bands in the region 5.8–5.9μ. In the spectrum of cellulose adipate (Figure 3B) a careful examination reveals the presence of two bands with maxima at 5.75 and 5.98μ. The longer wavelength band is very weak. In the corresponding spectrum of cellulose succinate only a single band at 5.75μ is revealed. The bands at 5.75 and 5.78μ arise from the expected ester vibrations. The band at 5.98μ in the spectrum of the cellulose adipate would appear to be the second band comparable to those found in the spectra of the reagent acids. Probably only at a high degree of substitution would these two bands be available for differentiation between esterification with a mono- and a dicarboxylic acid. The nonappearance of the carboxyl band at about 5.85μ indicates that both of these groups in the dibasic acids have been esterified. This, in turn, might suggest cross-linkage.

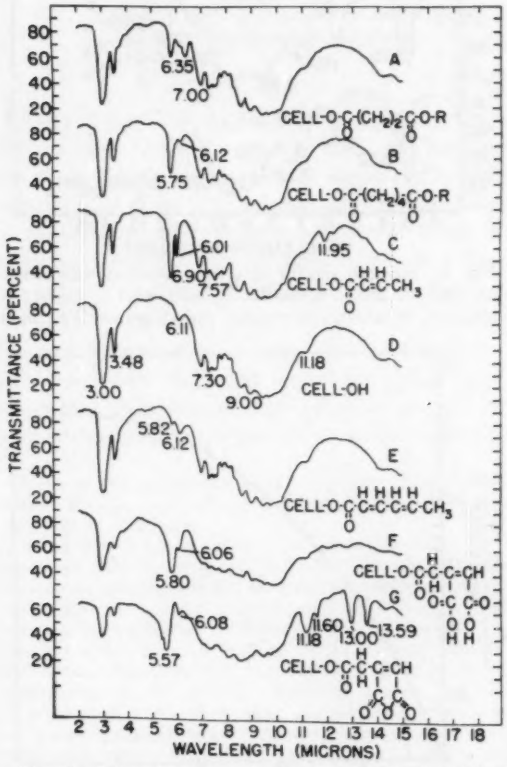

Fig. 3. Infrared spectra of cotton esterified with polybasic and unsaturated aliphatic acids: A, succinic; B, adipic; C, crotonic; E, sorbic; F, aconitic; G, aconitic (anhydride), and D, unmodified cotton.

Unsaturated aliphatic acids can be distinguished by the appearance of the weak but characteristic band associated with C=C stretching. This band is observed in the spectra of cellulose crotonate and cellulose aconitate (Figure 3C and 3F) at about 6.1μ. The rather broad shallow band, exhibited in the spectra of all unmodified cottons with maximum at about 6.15μ and arising from absorbed water, is replaced in the spectra of cotton modified by esterification with an unsaturated aliphatic acid, with a sharper band at distinctly shorter wavelengths. As seen in the spectra of cellulose sorbate, with a low degree of substitution (as evidenced by the relatively weak C=O stretching band at 5.82μ), this C=C stretching is not very intense. Evidence for modification by esterification can be established with a high degree of sensitivity. Identity of the esterifying agent as an unsaturated fatty acid can be accomplished only with considerably less sensitivity.

Cellulose aconitate anhydride (Figure 3G) can be distinguished readily, by means of infrared spectra, from the corresponding cellulose aconitate by the position of the C=O stretching at 5.57μ compared to the normal position at 5.75μ, in the spectra of cellulose aconitate (Figure 3F) and by the appearance of the distinctive bands with maxima at 13.0 and 13.6μ, arising from C–H bendings about the anhydride ring.

Esterification with an aromatic acid also can be recognized by the appearance in the infrared spectra of the strong C=O stretching near 5.75μ. This band is the most suitable for measurement of the degree of esterification. Esterification with an aromatic acid can be differentiated readily from similar modification with an aliphatic acid, and the various types of aromatic acids employed in the esterification can be differentiated. Cotton modified by esterification with an aromatic acid is characterized by appearance in the infrared spectrum of the C=C stretching vibrations of the aromatic ring bands in the 6μ region and by the aromatic ring band at about 14.2μ.

The phenyl group gives rise to two bands, C=C stretchings, at about 6.2 and 6.7μ, the band at the longer wavelength being the more intense. Conju-

gation in any fashion with the benzene ring, as in benzoic acid, gives rise to a third C=C stretching vibration at about 6.3μ. This conjugation of the benzene ring is accompanied by a decrease in the intensity of the band at about 6.7μ, so that the band at 6.25μ is the most intense [1]. In the 6.0–6.8μ region the spectrum of the cellulose treated with benzoic acid (Figure 4A) reveals two bands; a moderately strong band with a maximum at 6.25μ and a weak band at 6.35μ. Not more than a very weak inflection is observed at 6.7μ. These bands permit a ready differentiation between a cotton esterified with an aromatic and with an aliphatic acid.

Benzoylation can be distinguished from esterification with acids containing the phenylacyl group by examination of the bands found in the spectra just above 6.0μ and in the 13–15μ region. The spectra of the phenylacetic acid or the phenylundecanoic acid treated cotton, where there is no conjugation with the phenyl ring, reveal a strong band at 6.7μ, a weak band at 6.25μ, and nothing more than a weak inflection at 6.35μ (Figure 4B and 4C).

The spectrum of benzoylated cotton exhibits the ring vibration band characteristic of aromatic compounds at 14.1μ, not observed in the spectra of unmodified cotton. This band is also observed in the spectra of cotton treated with phenylacetic acid and phenylundecanoic acid with maxima at 14.4 and 14.3μ, respectively. Cottons modified with these two reagents also exhibit, in their spectra, a second band with maxima at 13.0 and 13.1μ. This band, not observed in the spectrum of the cotton treated with benzoic acid, has been shown to be characteristic of the phenylacetyl group [13]. It can also be used to differentiate between acylation with benzoyl and a phenylacetyl type reagent.

The infrared spectrum of the cinnamic acid treated cotton (Figure 4E) is differentiated from all others by the appearance of the strong band at 6.1μ, arising from a stretching vibration of the C=C group in the side chain. This band could be used both to identify this type of modification and to measure the degree of acylation with cinnamic type reagents, although, once identified, the amount of acylation could probably be more accurately estimated by use of the C=O stretching vibration.

In the spectra of several of the acylated cottons—cellulose phenylacetate (Figure 4B), cellulose phenylundecanoate (Figure 4C), and cellulose cinnamate (Figure 4E)—in addition to the strong

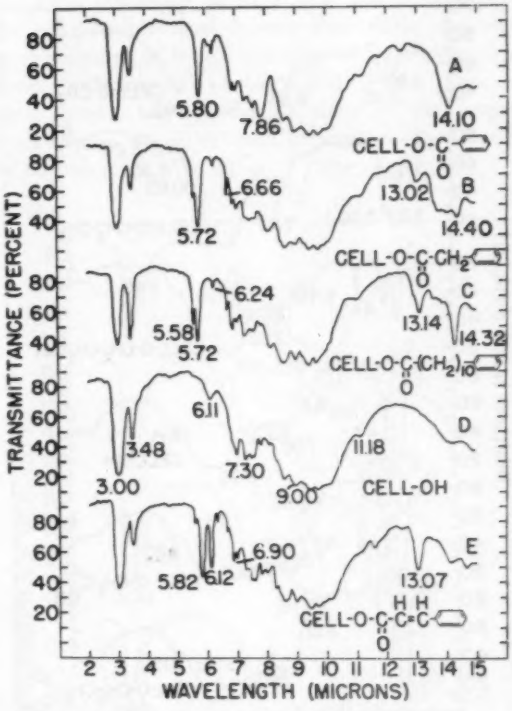

Fig. 4. Infrared spectra of cotton esterified with aromatic acids: A, benzoic; B, phenylacetic; C, phenylundecanoic; E, cinnamic; and D, unmodified cotton.

C=O stretching band at about 5.81μ, a second weaker band is observed at somewhat shorter wavelengths. In the spectrum of the cotton treated with cinnamic acid, strong bands are observed at 5.82μ, the expected position of the C=O of the ester, and at 5.58μ. The spectra of the phenylacetic acid and phenylundecanoic acid treated cottons exhibit bands at 5.6μ as well as at 5.7μ. These additional bands are not observed in the spectra of the pure acids. Their appearance, while unexplained, is connected in some way with the modification reaction. They may arise from the different positions of substitution on the cellulose molecule, i.e., either on the No. 6 (primary) –OH group or on the No. 2 and 3 (secondary) –OH groups. Another possible explanation is that they may represent substitution in the easily accessible amorphous region as compared to the less accessible crystalline region. In either case the appearance of two C=O bands *may* represent an opportunity to determine the position of substituents on the cellulose molecule or to differentiate between reaction in

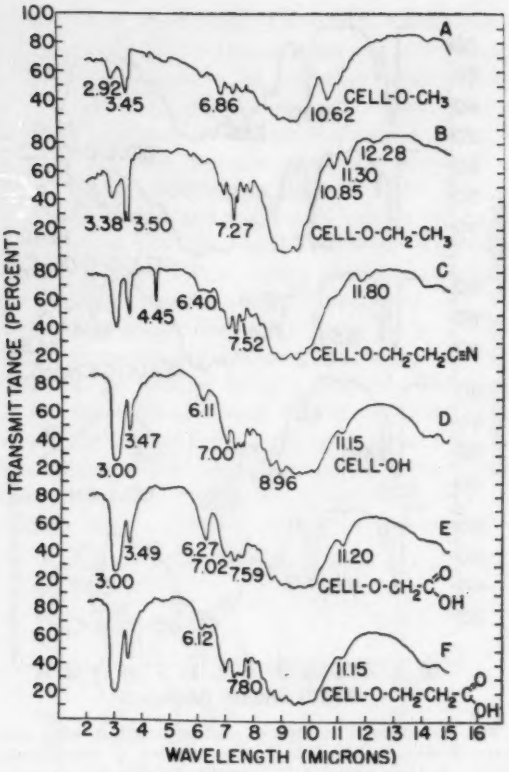

Fig. 5. Infrared spectra of etherified cotton: A, B, and C, methyl, ethyl, and cyanoethyl cellulose; D, unmodified cotton; E and F, carboxymethyl and carboxyethyl cellulose.

the amorphous as compared to the crystalline region. Considerable additional research is required to evaluate the potential usefulness of these bands. For such investigations, infrared spectra at considerably higher resolution than afforded with NaCl optics should be selected.

Etherification

The infrared spectra of several cottons modified by etherification reactions are shown in Figures 5 and 6. Most modifications of the spectra of cotton linters (Figure 5D) by methylation and ethylation (Figure 5A and 5B) can be correlated with the introduction of methyl and ethyl groups. The most pronounced change, however, is the decrease in the O−H stretching band. This strong band at 3.00μ in the spectrum of the unmodified linters is replaced by considerably weaker bands with maxima at 2.90μ in the spectra of methyl and ethyl cellulose. This shift in wavelength position has been discussed in the previous paper [11]. The presence of the $-CH_3$ group is indicated by the appearance of two bands between 3.4 and 3.6μ. The spectra of the unmodified cotton reveals only the single C−H stretching band at 3.45μ, while that of methyl cellulose shows bands at 3.45 and 3.55μ and ethyl cellulose at 3.38 and 3.50μ. The longer wavelength bands arise from C−H stretching of the $-CH_3$ group. Differences are noted also in the intensity of the C−H deformation band at 7.30μ, where the weak symmetrical deformations of the C−H groups of the unmodified cellulose are augmented by the stronger C−H symmetrical deformations of the $-CH_3$ groups at slightly shorter wavelengths.

Methyl and ethyl cellulose are differentiated from unmodified cellulose and from each other by characteristic bands at longer wavelengths. Methyl cellulose exhibits a characteristic band at 10.62μ, not found in the spectrum of ethyl cellulose. Three bands, at 10.85, 11.30, and 12.28μ, which are not observed in the spectrum of methyl cellulose, are exhibited in that of ethyl cellulose. None of these bands are seen in the spectrum of unmodified cotton. Colthup [2] assigns bands at just about 11 and 12μ to vibrations of the ethyl group, but makes no mention of a band near 10.62μ as characteristic of the methyl group. These bands undoubtedly could be used to provide some indication of the degree of methylation or ethylation of cotton.

In the spectrum of cyanoethylated cotton, a band at 4.45μ is observed which is not exhibited by untreated cotton. This band arises from a stretching vibration of the C≡N and can be used to identify a cyanoethylated cotton. Its intensity is a quantitative measure of the magnitude of etherification. In Figure 7 the degree of cyanoethylation, as measured by nitrogen content (by the macro-Kjeldahl procedure) is plotted against the intensity of the C≡N absorption band. The extent of cyanoethylation can be determined accurately from the infrared spectra of treated fiber or fabric. The infrared method is specific, determining only nitrile nitrogen, in comparison with a total nitrogen determination by the Kjeldahl procedure. The infrared method has, consequently, a particular advantage in the analysis of samples containing other nitrogen groups.

The spectra of cotton carboxymethylated with chloroacetic acid or carboxyethylated with acrylic

acid (Figure 5E and 5F) reveal no bands in the C=O stretching region from 5 to 6μ. The broad shallow band with maximum at 6.11μ in the spectrum of unmodified cotton is replaced, in the spectrum of carboxymethylated cotton, by a broad band with maximum at 6.27μ and in that of carboxyethylated cotton by two bands with maxima at 6.12 and 6.40μ. These bands arise from stretching vibrations of the COO^- ion. Carboxyalkylation reactions are conducted in an alkali medium resulting in the formation of the sodium salts rather than the free acids. This assignment has been verified by a comparison of the spectra of carboxyalkylated cotton before and after a hydrochloric acid wash. By this treatment the bands between 6.2 and 6.4μ, arising from the COO^- ion, are modified to the free acid C=O stretching mode at the normal position, about 5.85μ. This assignment also explains why, in the spectra of the carboxymethyl and carboxyethyl cellulose, no bands are normally observed in the 5μ region of C=O stretching.

The appearance of the C=O stretching of the free acid at 5.85μ after an etherified cotton has received a hydrochloric acid treatment can be distinguished from the 5.75μ band arising from the C=O of an esterification reaction. This provides a general method for differentiating, by means of infrared spectra, between a cotton modified by an esterification and an etherification reaction.

Carboxyalkylation with unsaturated acids, such as maleic and itaconic (Figure 6A and 6B), yields reaction products whose spectra are similar to those of methyl and ethylcarboxy cellulose. The reaction product with maleic acid exhibits bands between 6.1 and 6.3μ; itaconic acid products exhibit only a stronger band with maximum at 6.12μ. All of these bands are relatively weak. They would indicate etherification in alkali medium to produce a cotton modified with a sodium salt, an interpretation which could be confirmed by reexamination of the spectra after a hydrochloric acid wash.

Etherification with benzyl chloride or triphenylmethyl chloride to produce benzyl cellulose and trityl cellulose can be detected readily in the infrared spectra of the reaction products by the appearance of characteristic aromatic bands. Benzyl cellulose exhibits the weak 6.20 and stronger 6.66μ bands of nonconjugated aromatic compounds and, at longer wavelengths, the aromatic ring bands with maxima at 13.57, 14.34, and 14.90μ. Trityl cellulose exhibits the C=C stretching bands at 6.27 and 6.73μ which are considerably more intense than those observed in the spectra of benzyl cellulose and aromatic ring bands with maxima at 13.20 and 14.35μ. Any of these bands, but particularly those at the longer wavelengths, could be used to measure the degree of etherification with either of these reagents.

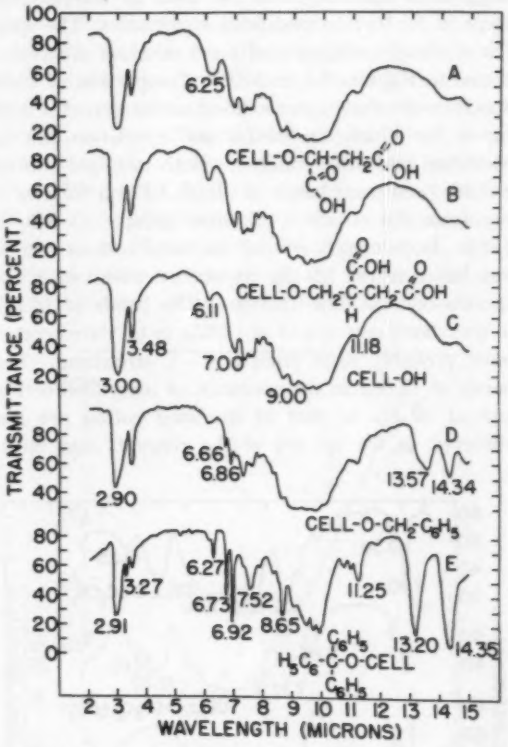

Fig. 6. Infrared spectra of etherified cotton: A, cellulose treated with maleic acid; B, cellulose treated with itaconic acid; C, unmodified cotton; D, benzyl cellulose; and E, trityl cellulose.

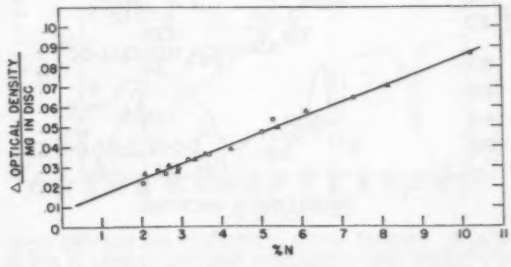

Fig. 7. Increase in intensity of 4.43 μ band with degree of cyanoethylation.

Mesylation, Tosylation, and Reactions of Cotton with More than One Reagent

Mesylation, the reaction of cotton with methyl sulfonyl chloride, and tosylation, reaction with *p*-toluene sulfonyl chloride, are among the older modification reactions of cellulose. These reactions recently have received renewed interest following the suggestion that they can be used as intermediate steps in the further modification of cotton. The spectra of mesyl cellulose and tosyl cellulose are reproduced in Figures 8A and 8B. Comparison of these spectra with that of unmodified cotton reveal several bands by which mesylation and tosylation can be identified and differentiated. Both modified cottons exhibit prominent bands at about 7.3 and 8.5μ, arising from the covalent sulfonate group, $-O-SO_2-R$ [15]. Both mesylated and tosylated cottons exhibit two bands in the 12–13μ region, not observed in the spectra of unmodified cottons. The bands at 13.25μ in mesylated cotton and at 12.62μ in tosylated cotton most probably arise from a C−S stretching. The bands at 12.08μ in the spectrum of mesylated cotton and at 12.30μ in that of tosylated cotton are not observed in the spectra of the reagents and must, therefore, arise from the C−O−S group formed during the modification reaction.

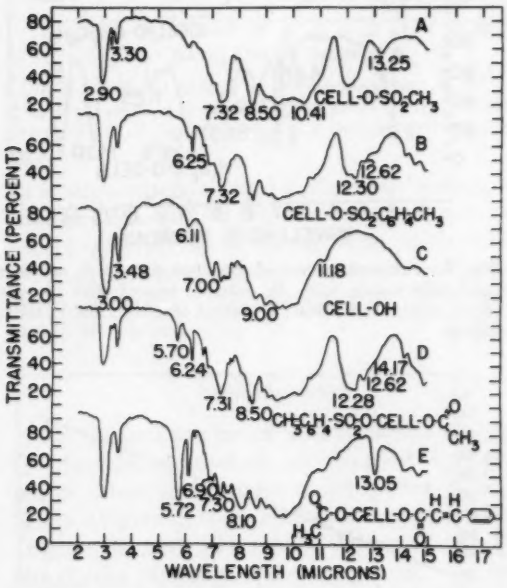

Fig. 8. Infrared spectra of mesylated and tosylated cotton and of cotton treated with more than one reagent: A and B, mesyl and tosyl cellulose; C, unmodified cotton; D, tosylated cellulose acetate; and E, cellulose acetate–cinnamate.

Mesylation or tosylation can be detected and quantitatively measured by use of either the sulfonate bands at 7.3 and 8.5μ or the C−S or C−O−S bands at longer wavelengths. As both the sulfonate bands occur in a region where the unmodified cotton exhibits some absorption, quantitative estimations could probably be made more satisfactorily using the longer wavelength bands. Curves relating the measured intensities of the absorption bands at 6.25μ and at 12.35μ of a series of cottons tosylated in varying degrees to the chemically determined sulfur content (by a Parr peroxide method of Fisher [4]) are reproduced in Figure 9. These curves show that either the band at 6.25μ or at 12.35μ can be used for a satisfactory quantitative determination of the degree of tosylation.

Mesyl and tosyl cellulose can be differentiated readily, by means of infrared spectra, by the appearance in the latter of the aromatic ring bands at 6.25 and 6.7μ. The spectrum of unmodified cotton exhibits the expected C−H stretching band at 3.4μ. This band is observed unchanged in the spectrum of tosylated cotton. The spectrum of mesylated cotton, however, reveals the second band with maximum at 3.30μ, very probably arising from a C−H stretching of the methyl group adjacent to the SO_3 (compare the spectra of methyl and ethyl cellulose, where a band somewhat longer than the 3.4μ band of unmodified cotton is introduced). The intensity of this band increases with degree of mesylation and can be used to identify mesylation, to differentiate it from tosylation, and to measure quantitatively the degree of mesylation. Tosylation can also be distinguished from mesylation by means of the 14.2μ aromatic ring band.

Figure 8D is the spectrum of cotton which was first acetylated and then tosylated. As can readily be seen, the detection or determination of the extent of acetylation by use of the band at 5.70μ is not affected by tosylation, nor is the detection or determination of tosylation, by means of the bands at 6.2, 7.3, 8.5, or 12.3μ, affected by partial acetylation. Similarly, in Figure 8E, the spectrum of a cotton modified first by acetylation and then by esterification with cinnamic acid, it can be seen that the extent of reaction with cinnamic acid can be determined by means of the 6.12μ C=C stretching band or the aromatic ring band at 13.05μ. Total esterifi-

cation of the samples can be had by measurement of the intensity of the 5.72μ C=O stretching band, and the extent of acetylation can be determined by difference. In cottons modified by two separate treatments, often it will be possible to detect and quantitatively measure the extent of each treatment.

Cottons Modified with Reagents which Introduce Nitrogen, Phosphorus, or Sulfur Groups

Several modifications of cotton introduce nitrogen, phosphorus, or sulfur into the cellulose structure. The spectra of a few reaction products, illustrative of these types, are shown in Fig. 10. Scherer and Feild [14] succeeded in introducing the amino group into cellulose by reaction of potassium amide on nitrocellulose. Later Guthrie [7] described the successful introduction of amino groups directly into cotton fabric by the use of 2-aminoethylsulfuric acid. As might be expected, the spectra of amino cellulose (Figure 10A) does not differ markedly from that of unmodified cotton. The stretching mode of the N−H group can be detected by a pronounced broadening of the strong O−H stretching band at 3.0μ; the N−H deformation is observed as a weak band at 6.30μ.

Carbamoylethylation of cotton by reaction with acrylamide [5] introduces into the spectra the strong Amide I band at 6.01μ arising from the C=O stretching in an amide (Figure 10B). This band can be used to identify this particular modification of cotton and, undoubtedly, could be used to measure the degree of substitution.

Despite the fact that the phosphorylated cotton, whose spectra is shown in Figure 10D, contained over 4% phosphorus, the spectrum is just about identical to that of unmodified cotton. There is no evidence for the intense, well characterized bands at 8.0μ, arising from the P=O stretching, nor between 9.5 and 9.7μ, attributable to a P−O−C stretching. Similarly, in Figure 10E, the spectrum of sulfoethylated cotton fails to reveal any evidence for the strong sulfone (-SO_2-) group, with bands between

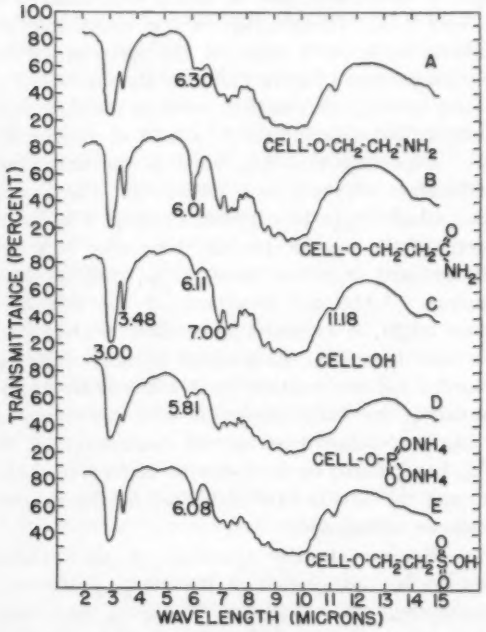

Fig. 9. Increase in intensity of 6.25 μ band, A, and 12.35 μ band, B, with degree of tosylation.

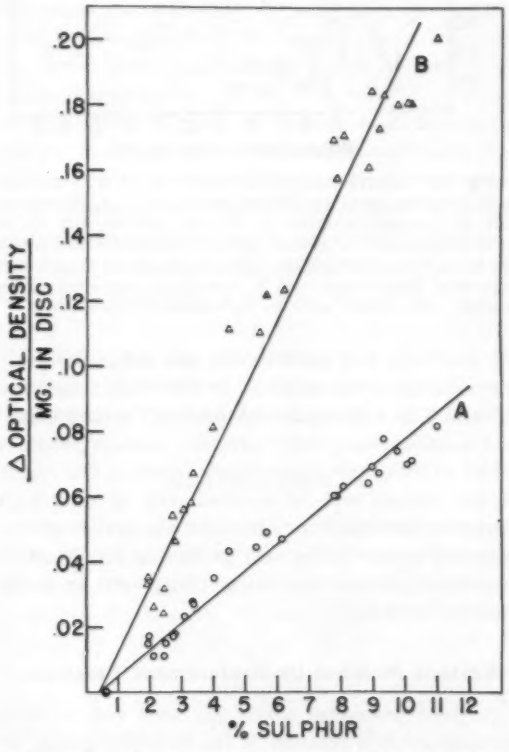

Fig. 10. Infrared spectra of cottons modified with reagents containing nitrogen, phosphorus, and sulfur: A, aminized; B, carbamoylethylated; C, unmodified; D, phosphorylated; and E, sulfoethylated cottons.

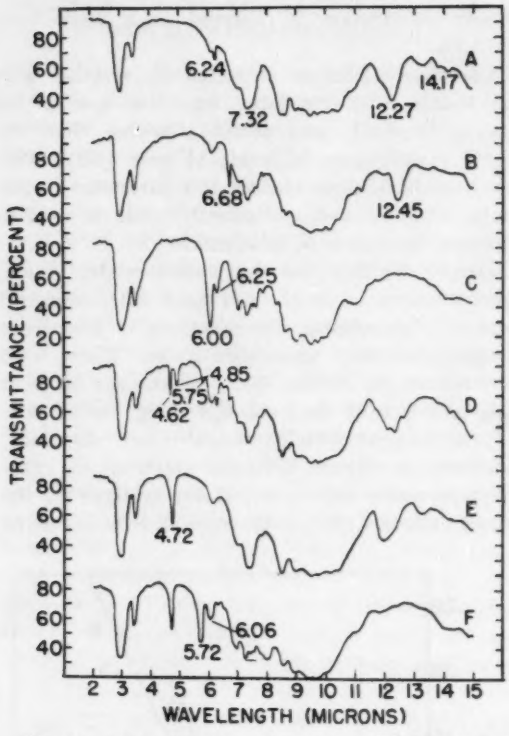

Fig. 11. Infrared spectra of cottons modified by replacement reactions, mesylated cotton treated with: A, the sodium salt of *p*-toluenesulfonamide; B, the sodium salt of *p*-methylthiophenol; E, sodium azide; C, cyanoethylated cotton treated with hydroxylamine; D, tosylated cotton treated with potassium thiocyanate; and F, acetylated, mesylated cotton treated with sodium azide in N,N-dimethylformamide.

7.5 and 7.6μ and between 8.6 and 8.8μ. Evidently the absorption of cellulose in this region between 7.5 and 9.5μ will mask even relatively strong bands, and modifications which produce reaction products which exhibit their characteristic bands in this region of the spectra will be detected only at very high degrees of substitution. Infrared absorption spectra does not appear to be very promising for detection of relatively small amounts of phosphorus or sulfur modified cottons.

Cottons Modified by Replacement Reactions

A third procedure which has been and is being investigated is a reaction of the hydroxyl group, by either esterification or etherification, with subsequent replacement of the modifying group with one of different character, thus producing an entirely new modification of the cellulose. Klein and Snowden [9] have shown how mesylated cotton can be the starting point in a series of reactions to replace the entire cellulosic hydroxyl group and introduce several new groups into the cellulose molecule. These types of reactions are also possible with tosylated cellulose as the initial material. Similarly, it has been shown that cyanoethylated cotton can be modified further to introduce into the cellulose molecule groups that cannot be introduced, or cannot be introduced in any concentration, by direct esterification or etherification. In Figure 11 are the spectra of a few modified cottons which illustrate these types of replacement reactions.

Figure 11A is the spectrum of mesylated cotton treated with the sodium salt of *p*-toluene sulfonamide. Reaction is evidenced by the decrease in the intensity of the mesyl bands at 7.3, 8.5, and 12.1μ. Introduction of the phenyl group into the cellulose molecule is verified by appearance of the aromatic C=C stretching bands at 6.25 and 6.70μ and by the aromatic ring band at 14.17μ. The sulfone group is detected in the spectra of mesylated cotton by the appearance of bands with maxima at 7.3 and 8.5μ (see Figure 8A). The spectrum of the reagent exhibits a comparable pair of bands with maxima at 7.6 and 8.7μ. Introduction of this group into the cellulose molecule is seen, in the spectrum of the reaction product (Figure 11A), by the appearance of a band at 8.6μ, intermediate between the 8.7μ band of the sulfonamide and the 8.5μ band of mesyl cellulose. Obviously this 8.6μ band is the unresolved combination of these two vibrations. The similar band, which might be expected at about 7.4μ in the spectra of the reaction product, cannot be very well differentiated from the strong 7.3μ band of mesyl cellulose. Additional treatment of the mesylated cotton might be expected to result in a shifting of this band from 7.3μ, its position in mesyl cellulose, toward 7.6μ, its position in *p*–toluenesulfonamide. Similarly, the band observed with maximum at 12.30μ is a distorted unresolved combination of the 12.1μ band, found in the spectrum of mesylated cotton, and the 12.40μ band exhibited by the reagent, *p*–toluene sulfonamide.

In Figure 11B the spectrum of the product obtained by replacement of the mesyl group with *p*–methylthiophenol is shown. This spectrum is characterized by the strong band with maximum at 6.68μ. This same band is observed in the spectrum of

p-methylthiophenol and can be used to identify the reaction product and again to measure the extent of the modification of the mesylated cotton. The band with maximum at 12.45μ is very similar to a band at the same wavelength in the spectrum of the reagent and represents incomplete resolution of this band from the 12.1μ band of mesylated cotton. A weak band with maximum at 11.20μ is characteristic of the reaction product. This band is not seen in the spectrum of mesylated cotton nor in that of the reagent, *p*-methylthiophenol.

Figure 11C is the spectrum of a cyanoethylated cotton treated with hydroxylamine. The introduction of the amide group is clearly evidenced by this spectrum with the appearance of the strong Amide I band (C=O stretching of an amide) at 6.0μ and the weaker 6.25μ Amide II band (N−H deformation of the amide group). The completeness of this replacement is shown by the absence of any trace of the sharp band of the nitrile group at 4.4μ (see Figure 5C).

The spectrum of a tosylated cotton treated with potassium thiocyanate is shown in Figure 11D. Two changes are seen in a comparison of this spectrum with that of tosylated cotton (Figure 8B). The C≡N group gives rise to two bands with maxima at 4.62 and 4.85μ, although the reagent, potassium thiocyanate, exhibits only the band at the longer wavelength. Either of these bands identifies the type of replacement reaction and could be used to measure its extent. A second band is seen in the spectrum of the reaction product with maximum at 5.75μ. This band is not observed in the spectra of either tosylated cotton or the reagent and would normally be assigned to a carbonyl group. Its appearance in the spectrum of this reaction product has not been explained.

One of the more recently achieved replacements has been the treatment of mesylated cotton with sodium azide. Introduction of the azide group is clearly seen by the appearance of the characteristic N≡N group as a strong band with maximum at 4.72μ. This band could be used readily for diagnostic purposes. Other than this band, the spectrum of the reaction product is identical to that of mesylated cotton.

The final spectrum in Figure 11 illustrates the use of infrared absorption spectra to identify a multimodified cotton. Figure 11F is the spectrum of a cotton which has been modified by three successive reagents. The sample was first acetylated, then mesylated; the mesyl group subsequently was replaced by treatment with sodium azide in N, N-dimethyl formamide. The acetyl group is identified by the usual carbonyl band at 5.72μ. Complete replacement of the mesyl group is shown by the absence of any trace of the 3.2 and 12.1μ bands. The azide can be identified (and measured) by the band at 4.72μ. Thus the presence, or fate, of each of the three reactants can be followed by means of infrared absorption spectra.

Summary

Infrared absorption spectra, obtained by means of the recently described KBr disc technique, have been applied to investigations of chemically modified cottons. By means of illustrative examples, it has been shown that such spectra can be used to qualitatively identify the type of chemical modification. Additional examples have demonstrated that quantitative measurement of the degree of modification can be obtained rapidly, simply, and accurately by means of such spectra. Table I is a list of 50 infrared absorption bands, and correlations with vibrating groups which give rise to them, summarizing the spectral characteristics which have been found most useful in investigations of cottons modified by esterification, etherification, and replacement reactions. As chemical modifications of cotton become more and more widespread, infrared absorption spectra appear to be ideal tools for identification of the type of modification, for quantitative estimation of the degree of modification, or as a means of following the kinetics of the modification reaction.

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TABLE I. Fifty Infrared Absorption Bands of Particular Significance in the Investigation of Modified Cottons

Unmodified cotton spectra—approx. position of band maxima—μ	Vibrating group most probably giving rise to observed absorption band	Modified cotton spectra—approx. position of band maxima—μ	Specific use in application of infrared absorption spectra to cotton and modified cotton
2.8–3.2	Free O—H and bonded O—H . . . stretching		Investigations of extent and type of hydrogen bonding [11]
	N—H stretching	3.0	Appears as a broadening of the 2.8–3.2μ O—H stretching band in the spectra of amino-cellulose
	C—H stretching of CH_3 group adjacent to SO_2 group	3.30	Identification of mesylation, especially to differentiate from tosylation
3.4	C—H stretching of C—H and CH_2 groups		Characteristic of all cottons
	C—H stretching of CH_3 group	3.45–3.55	Indicates methyl or ethyl cellulose
	C≡N stretching	4.45	Identification and quantitative measurement of cyanoethylation
	C≡N stretching	4.62 and 4.85	Characteristic of cotton modified by replacement reaction with thiocyanate
	N≡N stretching	4.72	Identification and quantitative measurement of cotton modified by replacement reaction with azide
	C=O stretching (anhydride)	5.57	Coupled with deformation bands in 13μ region, verifies that esterification with anhydride has been accomplished without breaking anhydride ring, e.g., aconitic anhydride
	C=O stretching	5.58	In absence of evidence of anhydride ring, may indicate position of substituent
	C=O stretching (ester)	5.75	Identification and quantitative measurement of esterification
	C=O stretching (acid)	5.85	If this band appears only after a HCl wash it can be used to differentiate esterification and etherification with an acid. Absence of this band after esterification with a dicarboxylic acid may indicate cross-linkage
	C=O stretching	5.98	May indicate esterification with a polybasic acid
	C=O stretching (amide)	6.00–6.06	Indicates modification to form an amide, e.g., carbamoylethylation with acrylamide; replacement of mesyl with N,N-dimethylformamide; replacement of cyanoethyl with hydroxylamine (see 6.30μ)
	C=C stretching (aliphatic)	6.10	Indicates modification with aliphatic unsaturated compound or aromatic compound containing unsaturated side chain
6.13	Absorbed H_2O		Characteristic of all cottons
	C=C stretching (aromatic ring)	6.25	Evidence for acylation with aromatic compound. Means for differentiation between tosylation and mesylation (see 6.70μ)

TABLE I. (Continued)

Unmodified cotton spectra—approx. position of band maxima—μ	Vibrating group most probably giving rise to observed absorption band	Modified cotton spectra—approx. position of band maxima—μ	Specific use in application of infrared absorption spectra to cotton and modified cotton
	N—H deformation (amide)	6.30	See 6.00–6.06μ
	COO^- ion stretching mode	6.2–6.4	Evidence for etherification with an acid and resulting salt formation
	N—H deformation	6.30	Probably indicates amino-cellulose or 2-amino-ethyl cellulose (see 3.0μ)
	C=C stretching of conjugated aromatic ring	6.32	Evidence for acylation with benzoic type reagent
	C=C stretching (aromatic ring)	6.7	See 6.25μ
6.96	CH_2 wagging		Measure of degree of crystallinity [11]
7.26	C—H deformation		Splitting of this band into two components indicates esterification with isobutyl
	S=O stretching of sulfonate, —O—SO_2—R group	7.3	Evidence for mesylation or tosylation (see 8.5μ)
7.46	O—H in-plane deformation		Characteristic of all cottons
7.58	O—H deformation and/or CH_2 wagging		Characteristic of all cottons
7.78	O—H deformation and/or CH_2 wagging		Characteristic of all cottons
	P=O stretching	8.0	Evidence for modification with phosphoryl—not observed in spectra of any modified cottons examined—see text
8.02	O—H deformation and/or CH_2 wagging		Characteristic of all cottons
	S=O stretching of sulfonate, —O—SO_2—R group	8.5	See 7.3μ
8.61	Unassigned		Characteristic of all cottons
8.95	Unassigned		Characteristic of all cottons
	P—O—C stretching	9.5–9.7	Evidence for modification with phosphoryl (see 8.0μ)
9.45	Unassigned		Characteristic of all cottons
9.71	Unassigned		Characteristic of all cottons
	C—H deformation	10.62	Evidence for methyl cellulose
11.20	CH_2 wagging		Measure of degree of crystallinity [11]
	C—H deformation	10.85 and 11.30	Evidence for ethyl cellulose
	C—H deformation	11.82	Evidence for esterification with isobutyric acid
	C—O—S stretching	12.1–12.3	Identification and quantitative measurement of mesylation or tosylation
	C—S (tosyl) stretching	12.62	Identification of tosylation
	C—H deformation	12.88	Evidence for esterification with capric acid
	$PhCH_2C=O$	13.0–13.1	Identification and quantitative measurement of esterification with phenylacetic acid type reagent
	C—S (mesyl) stretching	13.25	Identification of mesylation
	C—H bending about anhydride ring	13.0 and 13.6	Verifies esterification with anhydride (see 5.57μ)
	C—H bending about aromatic ring	14.1–14.4	Identification and quantitative measurement of modification with aromatic compound

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Phototenderization by Anthraquinone 2, 6-Disulfonic Acid of Cotton Duck Before and After Weathering

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Introduction

Phototenderization of cellulosic and synthetic fabrics treated with some vat dyes has been recognized and investigated for many years [2, 3, 6, 7, 8, 9]. Venkataraman [13], in his discussion of photochemical degradation of cellulose, points out that energy resulting from photosensitization of an active vat dye is transferred from the site of absorption to another at which a chemical reaction occurs. He reviews the suggestion that the mechanism of activity of anthraquinone dyes involves the preliminary reduction of quinone to the leuco compound, followed by the reoxidation of the leuco compound to the parent vat dye by atmospheric oxygen with the formation of hydrogen peroxide. A dye-peroxide may also form. The reduction of anthraquinone to anthrahydroquinone may be accomplished by an equivalent dehydrogenation of cellulose, causing some oxycellulose to form at this stage. The work of Lock, Bolland and Cooper, and others on the photosensitized oxidation of model compounds in the presence of sodium anthraquinone 2,6–disulfonate was reviewed recently [1]. Bolland and Cooper [5] found this anthraquinone dye to be particularly effective as a sensitizer in ethanol oxidation. Lock and others [1] showed two distinct processes for photo-oxidation based on their studies with glucosides and disaccharides; a break in the glycosidic linkage and oxidation of the sugar ring. This second process compared directly with photo-oxidation of alcohols studied first. Phototenderizing of cellulose appears to conform more closely to oxidation of ether linkages than does simple oxidation of –C–OH groups in alcohols. Anthraquinone sulfonic acid has been reported [12] to impart mildew resistance to cotton fiber by partial esterification of the fiber. Data obtained by this laboratory of field exposed fabrics treated with anthraquinone 2,6–disulfonic

acid for resistance to microbiological attack suggest that light could be the major factor affecting loss in breaking strength of the materials studied. This would be in accord with reports by other investigators for this and other anthraquinones.

Tenderization of the fabrics studied also could have been caused by hydrolysis of anthraquinone 2,6–disulfonic acid, resulting in the formation of sulfonic acid. The deterioration effects particularly associated with the formation of highly ionized acids by hydrolysis of organic fungicides containing halogen substituents were described by Rose et al. [11] for 2,2′ dihydroxy 5,5′ dichlorodiphenyl methane. Bayley [4] also showed that hydrolysis of copper naphthenate could account for loss in breaking strength of fabric so treated.

In addition to photolytic and hydrolytic causes for loss in breaking strength of fungicide treated materials, changes resulting from biolytic effects would also pertain when conditions of temperature and humidity are adequate for metabolic activity and growth of microflora.

The data relevant to the effects of anthraquinone 2,6–disulfonic acid presented herein were but a part of a broader program investigating the fungicidal efficacy of a variety of compounds applied to fabrics weathered for varying lengths of time at exposure sites in the Panama Canal Zone, at New Orleans, and in a tropical chamber.

Experimental

Materials and Methods

Square yard panels were prepared from 12.29-oz. cotton duck treated with 2.0 and 4.0% (nominal concentrations based on weight of fabric) anthraquinone 2,6–disulfonic acid. Aridex-L, a proprietary nondurable water repellent formulated as an emulsion of wax and an aluminum salt, was applied to all cloths. All test materials were dyed to OD-7 shade, but the composition of this dye is unknown. The control fabric was treated with water repellent and OD-7 shade dye only. Fabrics were weathered at all sites for 30 months. Every 3 months fabrics were removed from the site in the Panama Canal Zone (off ground, jungle shade) and from the Ft. Belvoir tropical chamber (intermittent incandescent illumination). Fabrics weathered at New Orleans (off ground, open field) were removed from exposure after 1, 2, 4, 8, 16, 24, and 30-month intervals). Fabrics were also stored in an enclosed makeshift jungle warehouse. Samples of these fabrics were removed every 6 months during the 30 months of tests for determination of breaking strength.

Ten test strips, raveled to 1 × 6 in., were prepared from each of the weathered test fabric panels. The strips were sampled according to a predetermined pattern to assure different warp and fill threads in each of the test strips. Breaking strengths of the test strips, as the index of deterioration, were measured with the long dimension parallel to the warp on a Model J Scott Tester after conditioning for 24 hr. at 72° F. and 63% relative humidity.

Standard deviations of the mean breaking strengths were computed for each treatment weathered for each designated interval at each test site. The average breaking strength obtained and the parameters of two standard deviations are shown graphically (Figures 1, 2, 3). The curves were fitted visually to the data as close as possible within the 95% probability limits indicated by two standard deviations.

Results

Breaking Strengths of Treated Unweathered Fabric

Anthraquinone 2,6–disulfonic acid was found to have a statistically significant effect on the breaking strength of the test material prior to weathering (Table I). The standard deviation and coefficients of variation computed for each of the test materials (Table II) were small, indicating a uniform effect resulting from homogeneous application of both concentrations of the test compound to the fabric. The significant reduction in breaking strength of the fabric upon treatment with anthraquinone 2,6–disulfonic acid is in accord with the report of Scholefield and Patel (1928, 1929) reviewed by Landolt [10] that tendering occurs with vat dyes even during the dyeing process if light is incident upon the material being dyed. The possibility exists that loss in tensile strength may be due to direct interaction of the compound with the fabric.

The mean break strength of the fabric treated with 4.0% anthraquinone 2,6–disulfonic acid is slightly higher than that of fabric treated with 2.0%. One would expect a more direct proportionality between concentration and effect. The apparent discrepancy in these data may be attributed to different amounts

of light incident upon these fabrics during processing and preparation for test. In any event, the least significant difference of 14.1 lb./sq. in. at the 1% level makes the difference between the two treatments nonsignificant and that of either fabric compared to the control significant.

Breaking Strength of Fabrics Weathered in the Jungle Shade, Panama Canal Zone

Tensile strengths of fabrics treated with 2.0 and 4.0% anthraquinone 2,6–disulfonic acid are related to time weathered (Figure 1) as quadratic curves established by visual best fit to the data. The curves for the two concentrations of the test compound curve downward, showing rapid loss in breaking strength at an essentially parallel rate, during the entire course of weathering. The change in breaking strength for the control versus time weathered was fitted also by a quadratic curve. Visual examination of the data for this control suggests curves other than the one given in Figure 1. The quadratic curve shown conforms to the calculation made for these data; viz., $y_c = 180.5 + 0.172x_1 - 0.098x_1^2$, significant at the 1% level. The initial rate of breaking strength loss for the control, accordingly, is slow compared to the rate of loss after 9–12 months. The scatter of the data in this instance makes difficult a visual fit of a curve to the data. However, the scatter due to variation is not unusual for a biological substrate undergoing biological degradation.

TABLE I. Analysis of Variance for Breaking Strengths Measured for Anthraquinone 2,6-Disulfonic Acid Treated 12.29-oz. Cotton Duck, Unweathered

Concentration applied to fabric, %	Mean breaking strength, lb./sq. in.
2.0	164.1
4.0	171.4
0 (Control)	189.7
*L.S.D. 1%	14.1

Source of variation	Degrees of freedom	Sums of squares	Mean variance	F†
Between treatments	2	3478.47	1739.29	13.28
Error	27	3397.40	125.83	
Total	29	6875.87		

* Least significant difference (L.S.D.) at 1% = 2.771 × 5.10 = 14.1 lb./sq. in.

† F required for 27 degrees of freedom for error and 2 degrees of freedom for lesser mean square at 5% = 3.35; at 1% = 5.49. Calculated $F = 13.82$, $P = .01$. Standard error of difference between 2 means $= \pm \frac{125.83 \times 2}{10} = \pm 5.10$. $t_{.01} = 2.771$.

Breaking Strength of Fabrics Weathered in Open Field, New Orleans

Cotton duck treated with 2.0 and 4.0% anthraquinone 2,6–disulfonic acid showed rapid loss in breaking strength for the first month of weathering (Figure 2). The rate of change of breaking strength thereafter is very slow. In contrast to this, the control fabric lost breaking strength more slowly than either of the treated fabrics for the first 8 months of weathering. During the interval between 8 and 24 months of weathering the breaking strength was lost slowly. At 30 months the control retained but 22.8 lb./sq.in. breaking strength.

Breaking Strength of Fabrics Retained in Tropical Chamber, Unweathered

Rate of breaking strength loss of anthraquinone 2,6–disulfonic acid treated cotton duck compared to the control fabric shows a striking similarity when exposed in a tropical chamber (Figure 3). The initial breaking strength of the treated fabrics were significantly lower than that of the control, as was

TABLE II. Standard Deviations and Coefficients of Variation for Breaking Strengths Measured for Anthraquinone 2,6-Disulfonic Acid Treated 12.29-oz. Cotton and Duck, Unweathered

Concentration applied to fabric, %	Mean,* lb./sq. in.	$\pm\sigma$,† lb./sq. in.	$\pm s$,‡ lb./sq. in.	C,** lb./sq. in.
2.0	164.1	4.2	13.2	8.0
4.0	171.4	3.7	11.8	6.9
0 (Control)	189.7	2.5	8.0	4.2

* All values are averages of ten break strength measures.

† σ = standard deviation of mean = $s/\sqrt{N}$ in which s is as defined in the next footnote and N is the number of break strengths measured for given sample.

‡ s = standard deviation of any one break strength for a given sample = $\sqrt{\Sigma d^2/N-1}$ in which Σd^2 is the sum of the deviations squared and $N - 1$ (degrees of freedom) for the number of values ($N = 10$) used to compute the mean.

** C = coefficient of variation = $(s/\bar{X})$ (100) in which s is as defined above and $\bar{X}$ is the average break strength obtained for all samples of a given treatment.

established by statistical evaluation of the treated unweathered fabrics. The best fit curves for breaking strengths measured through 30 months under these conditions of reduced and intermittent artificial illumination in the chamber show deterioration progressing at essentially an equal rate for each of the test fabrics. Compared to the evident influence of photosensitive anthraquinone 2,6–disulfonic acid on rate of loss of breaking strength of treated cotton duck, particularly when weathered at New Orleans (Figure 2), it may be deduced that fabrics maintained in a tropical chamber showed no phototenderization during the course of exposure. All fabrics

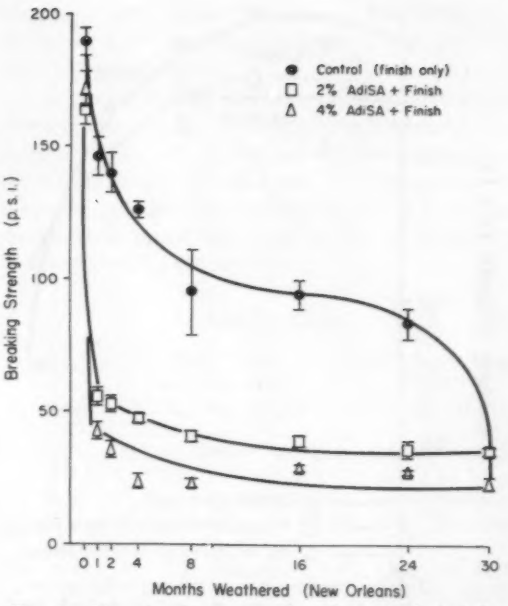

Fig. 2. Mean breaking strengths ± 2 standard deviations and visually fitted curves for breaking strengths of cotton duck (12.29 oz.) treated with 2.0 and 4.0% anthraquinone 2,6-disulfonic acid (AdiSA) and finish weathered in open field, New Orleans.

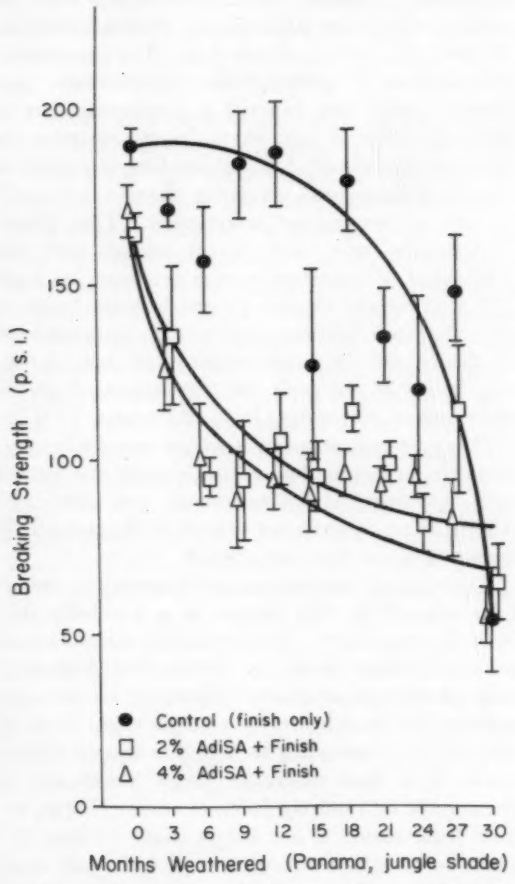

Fig. 1. Mean breaking strengths ± 2 standard deviations and visually fitted curves for breaking strengths of cotton duck (12.29 oz.) treated with 2.0 and 4.0% anthraquinone 2,6-disulfonic acid (AdiSA) and finish weathered in jungle shade, Panama.

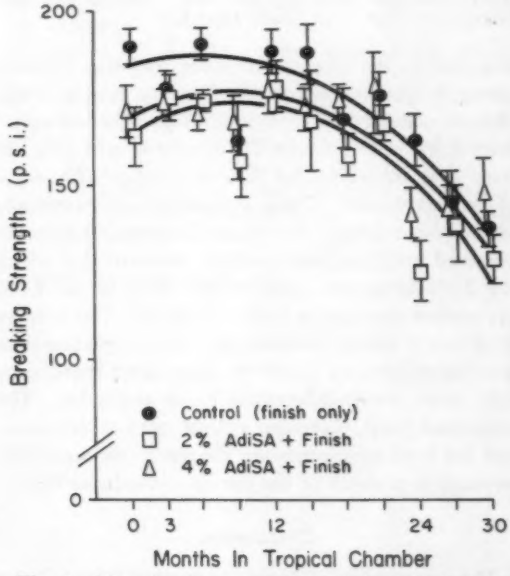

Fig. 3. Mean breaking strengths ± 2 standard deviations and visually fitted curves for breaking strengths of cotton duck (12.29 oz.) treated with 2.0 and 4.0% anthraquinone 2,6-disulfonic acid (AdiSA) and finish exposed in tropical chamber.

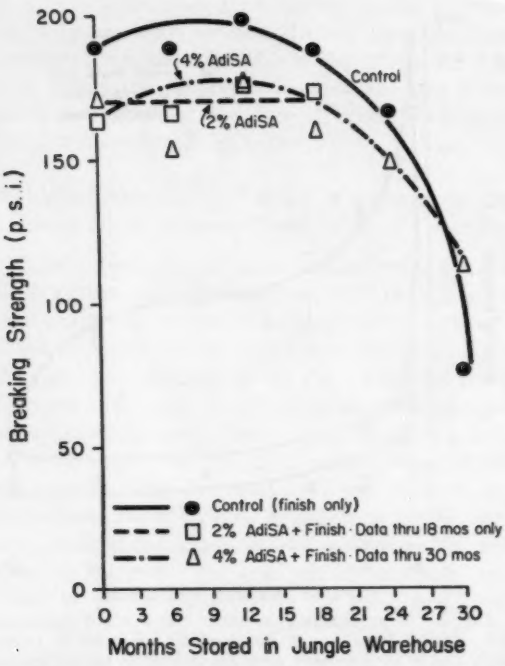

Fig. 4. Visually best fitted curves to mean breaking strengths of cotton duck (12.29 oz.) treated with 2.0 and 4.0% anthraquinone 2,6-disulfonic acid (AdiSA) and finish stored in an improvised jungle warehouse.

exposed in the tropical chamber and the breaking strength of the control in Panama jungle shade showed similar rates of loss. The effect obtained with 2.0% antraquinone 2,6-disulfonic acid was less than that measured for fabrics treated with 4.0% of this compound. These differences are essentially small. Accordingly, the change in breaking strength obtained after tropical chamber exposure for which the 2.0% treatment exceeded the effect of the 4.0% application may not be truly significant. The relative positions of curves obtained with their respective data were established by visual fit. Calculated regressions may show these differences to be negligible. The important point, therefore, is that rates of deterioration for both treatments are the same, the small differences in position of the curves notwithstanding.

Discussion

The weathering of fungicide treated fabrics is an important consideration for judgment of the suitability of the compound as a textile preservative. The response of the treated textile to weathering includes the totality of such components of outdoor exposure as photosensitization, leaching, alternate wetting and drying, microbial activity, hydrolysis of chemical compounds applied, and abrasion resistance. These factors remain to be separately defined and collectively applied as to their role in the deterioration of fungicide treated fabrics upon weathering. Photosensitivity of fungicides as well as dyes applied to cotton textiles may be the prime factor relevant to the stability of these compounds. The stability of these compounds in the presence of light might further affect the breaking strength of the cloth insofar as light energization of the compound weakens the molecular structure of cellulose. The studies referenced previously afford a reasonable basis for understanding and appreciating phototenderization of fabrics by anthraquinone dyes. The comparative deterioration of anthraquinone 2,6-disulfonic acid treated cotton duck exposed at weathering sites of relatively different light intensities demonstrates the probable dependence of rate of breaking strength loss on the photosensitive oxidative changes influenced by the anthraquinone investigated. This phototenderization may well be in accord with the mechanism of oxidative change proposed by Lock [1], Bolland and Cooper [5], and others based on their studies of light energized sodium anthraquinone 2,6-disulfonate and simple sugars or alcohols; it may also be in accord with the mechanism of phototenderization summarized by Venkataraman [13].

The evidence obtained remains essentially presumptive in nature but coincides with the known light sensitivity of anthraquinones and their subsequent effect by oxidative change on the strength of fabrics to which they are applied.

Hydrolysis of fungicides and the activity of ionized acids released by this process is a possibility that must be considered. Unfortunately, circumstances prevented closer study to differentiate hydrolytic from photochemical effects. However, on the supposition that some hydrolytic changes might occur at all sites, it is interesting to note that treated fabrics stored in a dark makeshift jungle warehouse in Panama showed entirely different curves (Figure 4) from those stored in the jungle shade (Figure 1), where some light did penetrate. If hydrolysis were a prime factor, the curves in the jungle shade and in the jungle warehouse should be similar. In fact, only the curves for the untreated controls are similar.

Compared to the rate of loss of breaking strength

obtained at the New Orleans site (exposure in full light), which was most rapid during the first month, that of fabrics weathered in the jungle shade in Panama was less rapid. The rapidity of loss in breaking strength of the treated as well as the control fabric when weathered at New Orleans appears to indicate the degradative effect of light on the fabric tested. Curves fitted to data of breaking strength change in the jungle shade show a more rapid rate of loss than was obtained in the tropical chamber. Whereas the loss in breaking strength of the control at the New Orleans site may have been influenced by light primarily, similar control fabrics exposed in the jungle shade and in the tropical chamber showed rates of loss probably predominantly influenced by microbial factors.

Summary

Cotton duck treated with anthraquinone 2,6-disulfonic acid appeared to deteriorate at rates directly related to the light intensities of the Panama jungle shade, New Orleans open field, and tropical chamber exposure sites. Treated fabrics showed a statistically significant reduction in breaking strength prior to weathering. This tenderization appears to be attributable to the effect of light incident upon the fabric during the time of treatment. The mechanism of the photo-oxidative changes may be that suggested by Bolland and Cooper [5] for ethanol in the presence of light energized sodium anthraquinone 2,6-disulfonate, or that reviewed by Venkataraman [13] for phototenderization effects of anthraquinone dyes. In strong light, rapid rates of breaking strength loss were obtained, to which linear functions best apply. In reduced light, breaking strength data were fitted best by quadratic functions. The former appears consistent with phototenderization. The latter condition prevails when deterioration results primarily from microbial activity.

The possibility that heat induced hydrolytic breakdown products of the anthraquinone compound were responsible in part for the loss in tensile strength of the fabrics cannot be ruled out. The data presented, however, indicate that hydrolysis was not a prime deteriorative factor compared to the probability of photo-oxidative changes.

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INDUSTRIAL SECTION

Basic Actions as an Approach to Textile Fiber Processing[1]

A Suggested Use of Symbols

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PRODUCTION of textile materials, in its earliest stages, was a matter of individual craftsmanship. The spinner, with his own hands, converted a roughly paralleled mass of fibers into a continuous strand of yarn by the twisting action of a rotating spindle onto which the product was immediately wound. This was a discontinuous operation resulting in only a few feet of yarn at a time. It involved multiple motions of the hands and fingers, with the hands and arms making relatively slow but extended movements while the fingers moved more rapidly and for only very short distances, of the order of a fraction of an inch, in the case of the hand controlling the fibers.

The observation of what went on during the hand spinning of a yarn was made difficult because of this fact. It is well known that small (and often rapid) movements of the fingers can be completely obscured by a sweeping gesture of the hand and arm. This was very probably the case here. The early observer was quite unlikely to have been trained in making accurate and detailed observations, and to him it may well have appeared that a large volume of fiber was pulled out—like molasses candy—into a fine strand, formed by the twisting action of the spindle. Hence, when the operation eventually was mechanized, the basic invention of two sets of rollers, operating at different surface speeds, to draw out or attenuate the strand, came into being. The industry, ever since, has been preoccupied with roller drafting. Perhaps its one redeeming feature is that it is continuous. There is little question in the mind of the modern textile manufacturer but that drafting tends to produce irregularities in the strand. This is overcome to some extent by doubling in usual practice. Just how effective this entire procedure is continues to be a matter for discussion and investigation.

It seems to the writer that the hand spinner was feeding small bundles (or even individual fibers in some cases) into the nip of the rotating strand. In other words, the fundamental action was one of fiber placement, rather than bulk fiber-mass attenuation. It may be well, therefore, to reexamine the nature of the basic actions involved in converting fibers into yarn and yarns into fabrics.

This is of immediate importance also because of the increasing number of textile fibers available to the industry and the differences in their physical and chemical properties, hence their behavior in end use. In its earliest form and later in cottage industry, there was maintained a direct physical or manual contact of the individual with the material he was using. There was an immediate sense of accomplishment, since the end product was at once visible and tangible. Faults could be removed or corrected almost as soon as they occurred. Maximum opportunity for exercise of judgment was afforded. A skill and pride of craftsmanship resulted which is almost entirely lost in modern mass production factories, where the

[1] Abstract of lecture delivered before the joint conference of The Fiber Society and The Textile Institute in Boston, September 6, 1957.

worker is rather a machine tender than a craftsman. The textile mills no longer have spinners or weavers on their payrolls. True, operators run spinning frames and looms, but they need have little or no knowledge of yarn or fabric structure, and they have practically no opportunity to exercise judgment or to make variations in the product produced. Quality control has become the function of the laboratory and supervisory staff. There is no sense of craftsmanship or particular achievement in relation to the material coming from the machine.

The textile industry has pioneered in what is now called automation. Feed-back devices of various kinds control tension, weight of material, replacement of empty bobbins, pressures, and concentrations. Machines have attained a large measure of automatic operation and accurate repetition of action by reason of skilled machine design and, increasingly, of electronic devices.

But much of this has not been horizontally integrated. Independent work has been done on cotton working machinery, wool working machinery, continuous filament and staple rayon and silk machinery —but far too little upon textile machinery as such. The industry has been preoccupied with machines and mechanisms related to the particular fiber in which it was interested. Now with many new fibers coming into use and with more and more pressure for the use of fibers of different kinds in combination with each other, a broader base of operation is called for.

Noteworthy progress has been made over the years in vertical integration within the textile industry, and some horizontal integration is presently evident in the combination of a number of plants, each handling different fibers and satisfying different end uses under one management. But the change has been in management and in operation of existing facilities as they are, rather than a basic approach to the processing of textile fibers at large.

It may be helpful to our thinking to recognize that classification of textile fibers into natural and man-made categories is increasingly a matter of degree rather than kind. To some extent, presently, all of our fibers, with the exception of asbestos, are man-made. Instead of combining materials in a container, later to be extruded somehow into filaments, we have combined fodder, rather carefully selected and supplemented by vitamins and minerals, in the body of the sheep, and the resulting extruded (*sic*) fiber resulting from careful cross breeding under control of the animal husbandryman comes to be available in desired distributions of length, diameter, and crimp, and can be classified into grades as to quality. If we substitute plant for animal, then we see the progress in producing cotton of desired length distribution, fineness, maturity, and strength by the agronomist. This has long been an important part of the program of the United States Department of Agriculture. Sericulture has become a scientifically controlled branch of the industry, and the startling difference between wild silk and cultivated silk bears evidence to this. Countries where the cultivation of flax has been a major factor in their economy have likewise nurtured plants to produce the optimum in fiber, rather than in meal or oil.

Modern research is dealing more and more with chemical and physical modifications of the so-called natural fibers—recognizing fully well that there are no natural textile fibers, but only those which man has wrested from nature for his own purposes. Even studies in fields apparently widely separated from textiles may well afford much information of great value to the textile technologist. Here, the work currently underway in biophysics and biochemistry on nerve and muscle fibers is of particular interest, not only as to the matter of details of morphology, but the ability of the fiber to respond to stimulus in important ways. In a sense, the textile finisher stimulates fibers chemically and physically to assume new forms and behaviors, but in the main, these are produced once and for all. The muscle and nerve fibers, however, are continually being excited into a wide variety of action and reaction, and most interestingly, are being continually renewed and rebuilt.

Now that we have increasing amounts of information on the structure, constitution, and behavior of fibers from a quantitative standpoint, we should be equally diligent in investigating our manufacturing procedures. If we can become divorced from preoccupation with certain fibers to the exclusion of others, and with machines and mechanisms, we can be freed to think of textile fiber processing in terms of the basic actions involved, and later, with the interactions between fiber and process equipment. To this end, our visualization of manufacturing operations must be accomplished through the use of symbols; particularly for reasons of simplicity, universality, ease of comparison, and speed. As will be shown, the necessary symbols are few in number;

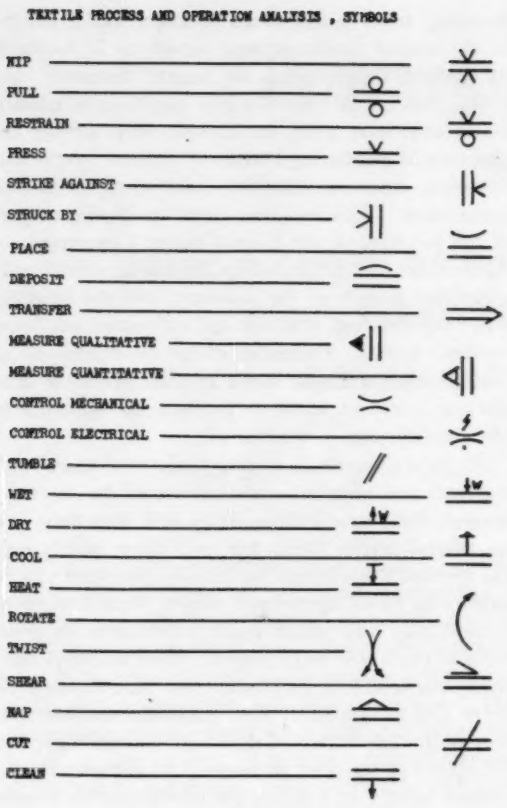

Fig. 1.

many of them are already in wide use elsewhere, with essentially the same meaning. They are usable by anyone without barrier of difference in language or background in machine design or operation. It should be understood clearly that no argument is being presented in favor of a particular set of symbols; rather, certain proposals are made which may or may not be subject to modification in the light of more widespread use. The important thing is the use of symbolism—not certain symbols in particular.

As an aid in symbolic study of basic actions, the process must be subdivided into operations (which, in some instances, are conveniently combined into subprocesses); the operations, in turn, should be divided into their fundamental action components. The approach to processing by way of a study of operations is not new. It has been the basis for work in instruction at the Massachusetts Institute of Technology in the field of textile processing for thirty years and has, for a long time, been actively advocated by Professor Morton of Manchester, England.

Typical operations would include grading, sorting, mixing, cleaning, paralleling, attenuating, combing, blending, twisting, doubling, opening, and forming. It should be noted that distinction must be made between the *operation* of combing, which is defined as separation of fibers, according to length, and the *subprocess* known as combing, which involves paralleling, attenuating, doubling, forming, and the operation of combing. There are also such subprocesses as carding, picking, drawing, roving, spinning, weaving, and the like. Each of these involves two or more basic operations in combination.

The important basic actions include nip, pull, restrain, press, strike against, struck by, position, transfer, deposit, qualitative measure, quantitative measure, mechanical control, electrical control, tumble, parallel, add to, take away, cool, heat, rotate, twist, shear, nap, cut, and double, as shown in Figure 1. These may be combined to give commonly occurring multiple actions such as draft, condense, doff, lap wind, bobbin wind, detach, piece-up, transfer through a restraint, intermittent feed, and the like, illustrated in Figure 2.

Gilbreth, in the field of motion study, devised a system of symbols called "Therbligs" which have proved invaluable. The fire protection engineer for many years has made use of a plan notation system of symbols to indicate the details of plant protection against fire as drafted. Proofreaders have long employed symbols to indicate changes and corrections in manuscripts. And in textiles, the fabric designer has used symbolism, in a sense, in the development of the point-paper method of indicating fabric pattern. Here, each row of squares vertically in the matrix represents a warp yarn, while each horizontal row of squares represents a filling yarn. It follows, therefore, that each individual square indicates a crossing of a warp and filling yarn. If the warp is uppermost at this point, the square contains a mark; if not, it is left blank. Furthermore, each line bounding a square represents a potential intersection—that is, a transfer of a yarn from one side of the fabric to the other (or from one layer of a multiple fabric to another). If it separates a marked square and an unmarked square above or below it, the warp yarn has changed position, whereas if it divides a marked square from an unmarked square on either side, the filling yarn has changed position. The

crossing of two lines—one horizontal and the other vertical, indicates a potential interstice. The magnitude and shape of the interstice depends upon the relationship of floats (a series of successive marked or unmarked squares) and adjacent intersections. Thus, to the trained designer interested in texture and geometry of fabric structure, as well as color and pattern, this symbolism gives considerable information as to the roughness (crepey character) or smoothness and the closeness or openness of the weave. Unfortunately, this is a much neglected phase of the fabric in three dimensions before it is woven. Such structures as honeycomb weaves, mock lenos, crepes, double fabrics, cords, and ribs can be recognized and handled easily. It also gives a universally understood means of communication throughout the world.

For the analysis of operations, subprocesses, and complete processes, the proposed symbolism makes possible rapid, compact, easily understood presentation of what happens to the fiber or yarn. It should be clearly appreciated that we are not so much interested in how it happens. This will be apparent to anyone acquainted with textile machines and their present use. The entire processing, machine type after machine type, for an entire process from fiber to fabric can be shown on a single sheet of $8\frac{1}{2} \times 11$-in. paper. This allows quick and easy comparison of entire processes with each other. It makes it simple to symbolize a desired operation on some unusual fiber or unusual combination of fibers, and then to compare this with the sequence of symbolized operations presently available. If a match is found, this is the machine to use; if not, then the modification of the machine to accomplish the purpose, or the need for an entirely new means, will be apparent.

With restrictions of existing machines and mechanisms removed through the use of the symbols, it also becomes possible to synthesize operations and processes and then to employ the best available data in such fields of engineering as fluid mechanics, aerodynamics, thermodynamics, statics, kinetics, materials handling, servos and controls, and automation to produce the required result. Supersonic vibrations, electrostatic fields, fluid jets and streams, masses of particles or beads, high density liquids, liquid metals, inactive or chemically active carriers, and various forms of energy are worth investigation; some of these are presently under investigation in various places.

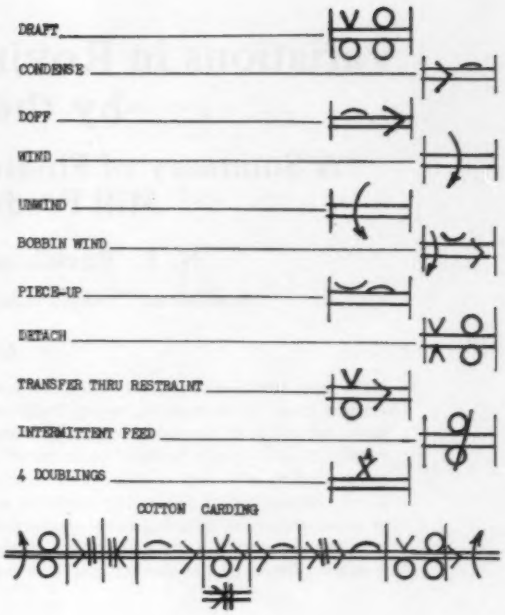

Fig. 2.

From the standpoint of training in logical and constructive as well as imaginative thinking, teaching forms an area of use for this technique. These symbols can be almost as important a tool for the textile technologist as the Arabic numerals and the conventional symbols for plus, minus, exponents, subscripts, integral signs, brackets, square root signs, etc. are for the mathematician or the symbols for the elements of the periodic table are to the chemist.

Craftsmanship is vanishing from the textile industry and may not return because of the pressures of quantity production, but imagination and clear thinking as to textile fiber processing can be stimulated and made more effective by rational and widespread use of symbolism to denote the basic actions which are involved in handling fibers for the eventual satisfaction of the ultimate consumer.

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Variations in Roving Weight Introduced by the Slubber

A Summary of Findings from the Analysis of Mill Produced Rovings

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Abstract

Conventional sizing tests of slubber roving involve the cutting and weighing of 12-yd. lengths from the outside layers of bobbins. In the present study, mill produced rovings were subjected to special sizing tests, whereby each bobbin was sized to the barrel. The results showed many unusual patterns of variation, which are described here. One frequent finding was that roving was excessively light or stretched at frame start-up.

A comparison of processing methods, test results, and correlation diagrams of the data is presented, from which general conclusions may be drawn concerning the processing of roving. Since the weight variation in the sliver fed was determined, the weight variation introduced by the slubber could be evaluated.

Introduction

As part of the statistical quality control program of a mill, it is often desirable to predict roving variation from the prior drawing sliver weight variation. When this procedure is done, however, the actual roving variation coefficient is often somewhat lower than the expected value. When, as a next step, yarn variability is estimated from the roving variation, an unexplained increase is often found. Obviously, when this situation is found to exist, it means that the full variability of the roving has not been revealed by the customary sizing test method.

This explanation is reasonable when one considers that the usual procedure used in routine mill sizing programs is to test only one or two 12-yd. lengths of roving from the outside of the bobbin. Since the sampling of the inside of the bobbin is inconvenient, this method is seldom used. On the other hand, since a roving bobbin produces several yarn bobbins, sizing tests of yarn will thus represent random samplings of spun product from all parts of the roving bobbin. With these ideas in mind, roving was tested to establish the amount of actual but "hidden" variation in weight of 12-yd. lengths throughout the entire roving bobbin.

This paper represents the findings from the work done on roving variation for a number of Institute member mills. The details are shown, however, only for carded stock produced on Saco-Lowell FS-2 and J-3 slubbers, because for the others not enough combed stock sets were available to prepare valid correlations, many roving sets represented only two or three frames of a particular type, and some sets represented fiber stock other than cotton.

While the majority of roving sets analyzed represent actual mill specimens produced at the mills and tested at the Institute, four sets represent bobbins both produced and tested at the Institute, in conjunction with a thesis by Moss [3]. These sets are identified here as Set Nos. 6–9. Test results and processing data are shown in Table I.

The only specific prior work found in the literature on "hidden roving variation" which had a bearing on the present study was that of Rudnick [4], who used statistical methods of analysis of variance to prove significant differences in weight variation within the roving bobbins. From the data it was concluded that the throughout-bobbin or "hidden" roving variation should be taken into consideration when comparing different lots of roving.

[1] Mr. Hicks is now with Fieldcrest Mills, Leaksville, North Carolina. He was a graduate student at the Institute when the work reported in this paper was carried out. The paper was written primarily by the senior author.

TABLE I. Roving Test Results and Processing Data

All frames equipped with G-38 cone

Roving set no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hank roving	0.95	1.00	1.00	1.00	1.00	1.50	1.50	1.50	1.50	1.50	1.75	1.80	2.00	2.00	2.00
Frame make	J-3	FS-2	FS-2	J-3	J-3	FS-2	FS-2	FS-2	FS-2	J-3	FS-2	FS-2	FS-2	J-3	J-3
Test results															
% V_d of roving*	1.21	1.38	0.81	1.40	0.84	1.18	1.11	1.21	1.06	2.06	1.24	1.64	0.97	1.50	1.48
% V_o of roving*	1.72	1.96	1.16	1.70	1.63	1.61	1.33	1.50	1.31	2.47	1.37	2.85	1.30	2.26	2.31
% V_d of sliver fed*	0.90	——	0.29	1.18	0.94	0.56	0.76	0.83	0.46	1.06	0.62	1.22	0.33	0.60	0.52
% V_o of sliver fed*	1.23	——	1.02	1.77	2.22	1.75	1.12	1.40	0.76	1.61	0.91	2.54	1.33	——	2.41
Processing data**															
Bobbin size	11×5.5	12×6	10×5	10×5	10×5	10×5	10×5	10×5	10×5	10×5	9×4.5	9×4.5	9×4.5	10×5	10×5
Taper gear	18	17	18	17	17	18	18	18	18	17	20	18	19	17	17
Tension gear	29	28	58	44	44	37	38	39	40	48	39	40	36	43	31
Twist multiple	1.37	1.15	1.17	1.22	1.22	1.30	1.30	1.30	1.30	1.35	1.23	1.25	1.29	1.30	1.32
Twist %	62.8	52.2	53.2	55.4	55.4	55.2	55.2	55.2	55.2	57.3	50.9	51.5	52.2	53.0	53.4
Coils/in.	9	10	8.5	14	12.5	10.4	10.4	10.4	10.4	13.5	11	11.5	12	——	12
Draft															
1–2	2.0	——	5.7	5.4	5.4	3.6	3.6	3.6	3.6	2.0	4.8	——	8.9	3.1	——
2–3	1.05	——	1.2	1.05	1.01	2.5	2.5	2.5	2.5	1.05	2.4	——	1.5	1.05	——
3–4	3.8	–	–	1.15	1.15	–	–	–	–	4.9	–	–	–	4.2	–
Total	7.0	5.8	6.8	6.5	6.2	9.1	9.1	9.1	9.1	10.2	11.5	15.2	13.3	13.6	12.4
Roll settings, in.															
1–2	1.2	2.0	1.2	1.3	1.3	2.1	2.1	2.1	2.1	1.1	2.0	2.0	2.0	1.3	1.3
2–3	1.8	1.4	1.6	1.7	1.7	1.4	1.4	1.4	1.4	1.8	1.3	1.4	1.3	1.8	1.7
3–4	1.4	–	–	1.7	1.7	–	–	–	–	1.5	–	–	–	1.5	1.7
Front roll r.p.m.	168	158	220	217	305	165	165	165	165	154	176	148	166	142	146
Flyer r.p.m.	775	675	900	943	942	925	925	925	925	895	1017	888	107	918	1004
Stock**															
Staple in 32's in.	33	34	34	34	38	34	34	34	34	33	34	34	34	34	35
Grade	M	M	M	SLM	M	M	M	M	M	M	M	M	M	M	M

* % V = Percent coefficient of variation, d = within-spindle, o = frame-overall.
** As reported by the mills.
—— = No data submitted.
– = Not applicable.

Sampling and Testing

For each roving set tested, six bobbins were selected from the roving frame. Three bobbins were from the front row and three bobbins were from the back row. Bobbins were spaced so as to represent spindles near the two ends of the frame and in the middle. In addition, the sliver in back of each spindle was sized. Eight 1-yd. lengths were sized from each such can in the test.

Testing was performed in the Merchants' Laboratory of the Institute, using a motor-driven roving reel with a built-in yardage counter. Each bobbin was stripped by cutting it into successive 12-yd. lengths until bare; the individual segments were weighed after a 24-hr. exposure to standard atmospheric conditions of 72° F. temperature and 65% relative humidity. The weights from the 12-yd. lengths were used to compute variation coefficients. The combined results of ten 12-yd. lengths were averaged and plotted to show trends in roving weight of successive 120-yd. lengths. During the testing of some of the later sets of roving, a shortcut sampling method was used whereby successive 12-yd. lengths and 108-yd. lengths were reeled. The weights from the 12-yd. lengths were again used to compute variation coefficients, while the 108-yd. and 12-yd. lengths were combined for the purpose of showing trends in roving weight of successive 120-yd. lengths. No noteworthy loss in reliability as a result of the shortcut method was found to exist, and the data from the two methods may be considered substantially identical for the purpose of this analysis.

The accuracy of reelings was tested. It was found that the tension during reeling affects the length of roving and thereby the unit weight. This effect, however, can be ignored if the effect of stretch is a consistent one, since the analyses were concerned with *variations* about the average level of weight, and not with the *absolute* weight itself. In order to test the consistency of the effect of stretch, a special reel was constructed, whereby roving was unwound while resting on a pair of horizontally aligned rotating drums, each $\frac{1}{2}$ yd. in circumference, thus eliminating all unwinding tension. The roving thus unwound, while differing by approximately 2% in average weight, showed variation coefficients which

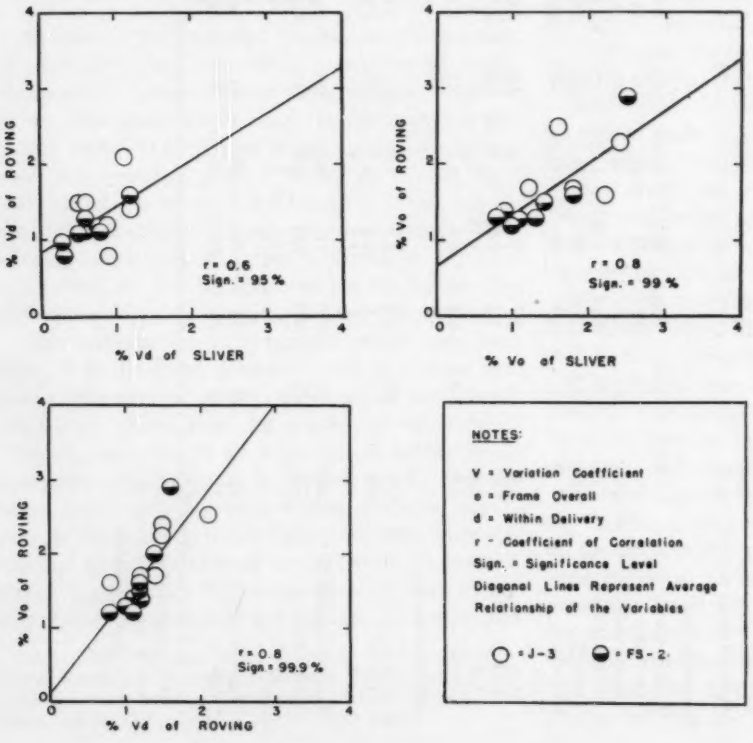

Fig. 1. Correlation of variation coefficients; sliver and roving.

agreed very closely with those found by means of the ordinary tension reel equipped with motor drive. It was thus concluded that the reeling on an ordinary roving reel is proper for use in evaluating variations in 12-yd. lengths of roving weight throughout the bobbin.

Variation Coefficients

Variation coefficients, %V, were computed for the following components of variation:

1. Within-spindle variation of roving produced, based on 12-yd. weighings throughout the bobbin.
2. Frame-overall variation of roving produced, based on 12-yd. weighings throughout the bobbin.
3. Within-spindle variation of sliver fed, based on 1-yd. weighings.
4. Frame-overall variation of sliver in back of the roving frame, based on 1-yd. weighings.

It is evident that the within-spindle variation of sliver represents the input variation into within-spindle variation of the roving, while the overall variation of the sliver represents the overall input variation into the roving produced. However, these values of input variation must be considered only approximate; there are inaccuracies inherent in testing; there are "errors" or fluctuations due to chance effects of sampling; and the 1-yd. lengths of sliver do not necessarily correspond to the 12-yd. lengths of roving tested, since the draft is not always 12 from sliver to roving.

All these effects are considered minor, since care was taken to perform accurate testing by means of a motor-driven roving reel, as discussed above; enough testing was done to reduce sampling errors to a practical minimum; and the effect of changing yardage lengths is usually only about 0.2% for the drafts involved [2].

All variation coefficients were computed by the statistical method of analysis of variance and vector addition of variance components, using the techniques given by Duncan [1]. This method is considered to yield the best estimates of the true variation coefficients from the samples of sliver and roving tested. The coefficients thus obtained for the sliver and roving are shown in Table I, together with the pertinent processing data.

Correlations

In order to derive general conclusions from the roving weight variation data, the correlation diagrams shown in Figure 1 were prepared for the following relationships: (1) relation between within-spindle variation of sliver and within-spindle variation of roving; (2) relation of frame-overall variation of sliver and frame-overall variation of roving produced therefrom; and (3) relation of within-spindle variation of roving and frame-overall variation of roving.

Examination of the diagram in Figure 1 shows that while (2) and (3) above gave good correlations

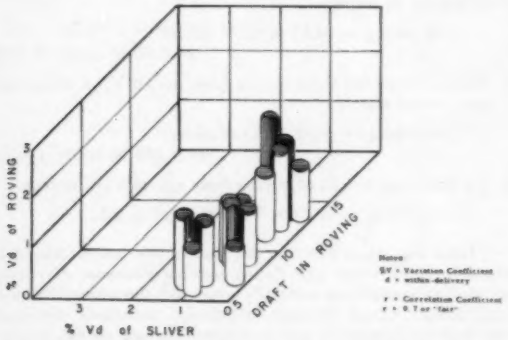

Fig. 2. Effect of sliver variation and draft on roving variation.

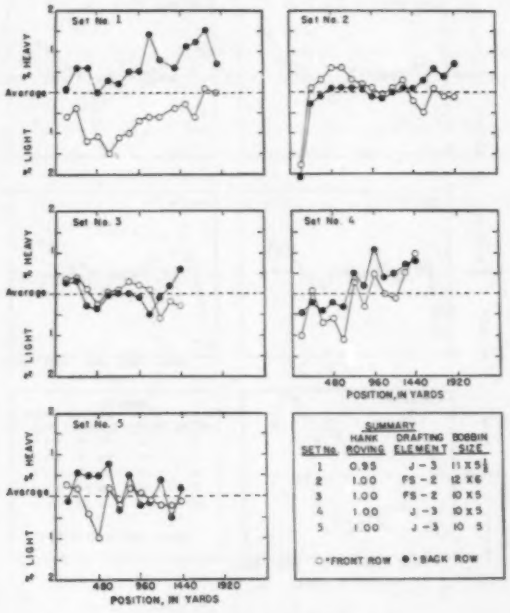
Set No. 1
Set No. 2
Set No. 3
Set No. 4
Set No. 5
% HEAVY
Average
% LIGHT
480 960 1440 1920
POSITION, IN YARDS
SUMMARY
SET No. | HANK ROVING | DRAFTING ELEMENT | BOBBIN SIZE
1 | 0.95 | J-3 | 11 X 5½
2 | 1.00 | FS-2 | 12 X 6
3 | 1.00 | FS-2 | 10 X 5
4 | 1.00 | J-3 | 10 X 5
5 | 1.00 | J-3 | 10 5
○ = FRONT ROW ● = BACK ROW

Fig. 3. Trends in roving weight.

at high significance levels, the relationship in (1) was only borderline. This finding was believed to be the result of the fact that draft in roving is a variable which should be included in this relationship. Accordingly, the three-dimensional correlation shown in Figure 2 was prepared to include the effect of draft. It will be noted that a fair degree of correlation thus is shown to exist.

Estimating Equations

For all the individual points shown in Figures 1 and 2, mathematical equations were derived to describe in a single line, or plane, the average relationship found. The resultant estimating equations are shown in Table II. These equations should be of considerable practical value to the mill, for they make it possible to find the normally expected variations on the roving frame. Against these normally expected variations, the actual variations obtained in the mill can be compared and evaluated. Thus, any place where excess variation is introduced, be it within-spindle or frame-overall, can be isolated quickly, so that corrective action can follow. The actual effectiveness of this approach has been demonstrated in over 30 successful mill applications.

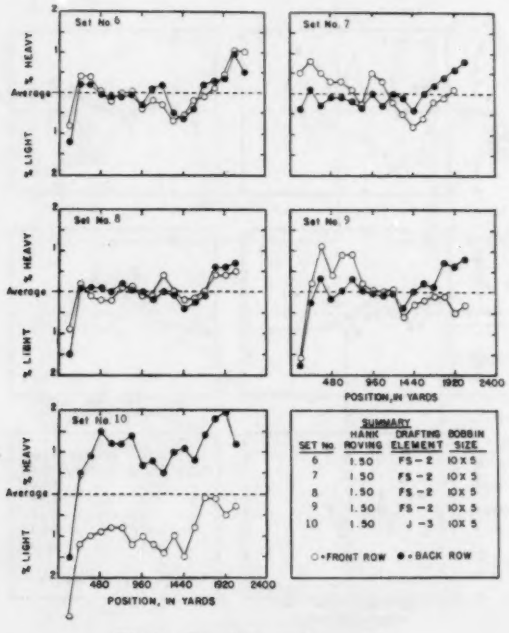
Set No. 6
Set No. 7
Set No. 8
Set No. 9
Set No. 10
% HEAVY
Average
% LIGHT
480 960 1440 1920 2400
POSITION, IN YARDS
SUMMARY
SET No | HANK ROVING | DRAFTING ELEMENT | BOBBIN SIZE
6 | 1.50 | FS-2 | 10 X 5
7 | 1.50 | FS-2 | 10 X 5
8 | 1.50 | FS-2 | 10 X 5
9 | 1.50 | FS-2 | 10 X 5
10 | 1.50 | J-3 | 10 X 5
○-FRONT ROW ●-BACK ROW

Fig.4. Trends in roving weight.

Trends in Weight

Trends in the weight of 120-yd. lengths of roving, with relation to the average weight, from barrel to full bobbin, are shown in Figures 3, 4, and 5 for each of the roving sets included in this study.

One predominant occurrence on many sets is that of light roving at start-up. This condition has been shown to be subject to improvement by trial tests, using different tension gears, cone gears, crown gears, coils-per-inch and cone-belt starting positions. No general method for eliminating this condition has been found as yet; therefore the finding of optimum processing conditions is dependent upon mill trials.

Aside from the quality benefits of lowered yarn variation resulting from a reduction or elimination of light roving at start-up, a mill may also derive cost savings, since excessively light roving at start-up is apt to cause creel-breaks. Upon correction, increased spindle assignments per operator might become possible.

Conclusions

The general conclusions, derived from the analyses of roving weight variation throughout the bobbin made in this study, are as follows:

1. One of the most frequent findings in testing for "hidden weight variation" is the production of excessively light roving at start-up for the first 100–

TABLE II. Estimating Equation for Roving Variation Derived from the Sliver and Roving Test Correlations *

1. To find expected % V_d of roving from actual % V_d of sliver and draft in roving:

   V_d of roving = (0.67 × V_d of sliver) + (0.06 × draft) + 0.19

2. To find expected V_o of roving from actual V_o of sliver and draft in roving:

   V_o of roving = (0.61 × V_o of sliver) + (0.055 × draft) + 0.24

3. To find expected V_o of roving from actual V_d of roving:

   V_o of roving = (1.29 × V_d of roving) + 0.12

* These equations describe the lines of average relationship found from the sliver and roving test correlations; they may be used in computing normally expected throughout-bobbin variations. Actual throughout-bobbin variations obtained can then be compared and evaluated against normal expectation. % V = coefficient of variation, %; % V_d = % V within spindle; % V_o = % V frame overall.

200 yd. Such roving may be responsible for poor quality in the form of undue yarn variation and excess labor costs resulting from high spinning creel breaks at light roving positions.

2. Reduction in the amount of excessively light roving at start-up is possible by using the proper cone-belt starting position, tension and lay gearing, cone gearing, and twists. Because no generalized engineering formulas have been developed, proper settings and gear combinations must be discovered by actual mill tests.

3. For carded rovings between 1.0 and 2.0 Hank inclusive, produced on Saco-Lowell FS-2 and J-3 roving frames, prediction equations have been developed which express an average relationship in variations; they may be used to determine whether roving is in conformance with, in excess of, or better than average in regards to weight variation of 12-yd. lengths.

Acknowledgments

The authors wish to acknowledge the overall assistance and advice given by Dr. Jack Compton, Technical Director of the Institute. Also, the help of Mr. H. A. Mereness and the Merchants' Laboratory personnel in testing the roving is gratefully acknowledged. All testing was performed as part of Institute member mill service request work, except for four sets of roving tested by Mr. William E. Moss as part of his graduate thesis [3]. The work of Mrs. M. Connor and Mrs. T. Rucker in performing the statistical computations, and of Mr. John Bevilacqua in drawing up the diagrams, is also acknowledged.

Special appreciation is due the participating Institute member mills, who permitted use of the test results on their rovings, in preparing the consolidated findings and analyses herein.

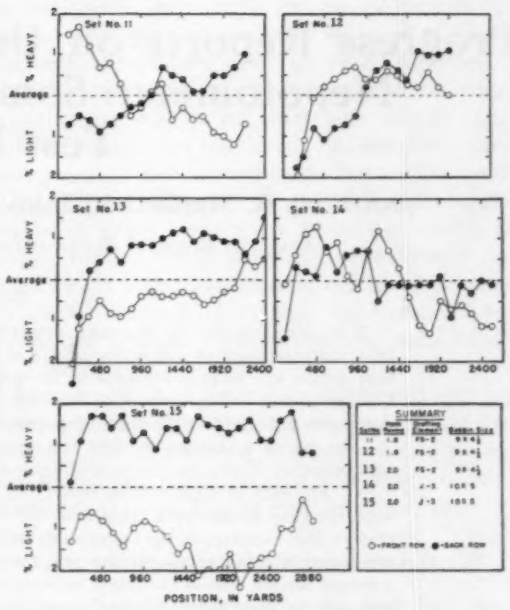

Fig. 5. Trends in roving weight.

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Progress Reports on Use and Application of the Nepotometer: Some Factors that Affect Test Results[1]

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Abstract

The Nepotometer is in many respects a miniature card designed to simulate on laboratory samples of cotton the effects of actions encountered during the carding operation which are largely responsible for nep formation. It was developed at the North Carolina State College School of Textiles, under a contract with the U. S. Department of Agriculture, to predict the nepping potential of cottons.

The use of a standard-weight test specimen does not necessarily produce a standard weight web. There may be considerable differences in this respect among different cottons. For each of eight cottons tested, the web weight and log of neps per grain increased with increase in specimen weight in the region tested between 17.5 and 27.5 grains inclusive, the increases being linear with no indication of curvilinearity. Since evaluations are based on comparison of the webs with appearance standards, the production of a constant weight web in the test is believed to be necessary. The possibility of controlling web weight by consideration of some readily determined property such as Micronaire reading or Fibrograph upper half mean length, or a combination of these, appears promising. Two simple equations have been derived for determining the specimen weight to use for a fixed web weight—one based on Micronaire reading and the other on upper half mean length.

Good correlation was found between the log of neps per grain and the photographic standards when the web weights were approximately constant. The regression curve above Grade 1 was essentially a straight line. Neppiness standards following a regular progression can be obtained from the present photographic grades by adding another grade between the present Grades 1 and 2.

Introduction

Neps have always been a serious source of trouble when manufacturing cotton yarns and fabrics. Their presence not only causes difficulty in mill operations and dyeing but also lowers the quality and value of the manufactured products.

Nepping tendencies vary greatly among different cottons and are not fully predictable even when the commonly measured fiber properties are known. Length, fineness, and maturity are well known to be important contributing factors, both alone and in combination [2], but there are other more obscure factors that are not always recognized. Webb and Richardson [7] included six fiber properties in developing their equation for estimating the number of neps in card web. Pearson [6] showed that even though high correlation was obtained with length, fineness, and maturity, cottons are frequently found which show seemingly anomalous behavior which must be attributed to properties associated with variety and environment that are not usually measured. De Meulemeester and his colleagues at the University of Ghent [4] recently have reported studies showing the important role played by stiffness, as measured from stress–strain data on cotton fibers.

The need for a practical laboratory instrument to evaluate the nepping potential of raw cotton led to the development of the Nepotometer[3] at North

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 12, 1958.

[2] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

[3] The mention of trade products does not imply their endorsement by the Department of Agriculture over similar products not mentioned.

Carolina State College under contract with the United States Department of Agriculture. This instrument was first described before the Cotton Research Clinic in 1954 [3].

This paper presents a progress report on some studies conducted with the Nepotometer at the Southern Regional Research Laboratory to determine the effect of different factors on the test results. The ultimate purpose of these investigations is to establish the most satisfactory test procedure with this instrument for evaluating the nepping tendencies of different cottons.

Instrument and Test Procedure

The Nepotometer, shown in Figure 1, is in many respects a miniature card designed to simulate on laboratory samples of cotton the effects of actions encountered during the carding operation which are largely responsible for nep formation.

The original test involves hand carding a representative specimen weighing 25 gr. to form a 5 × 5-in. pad which is then fed into the instrument. The total operating time is 4 min., including the time spent in feeding in the specimen. The web on the upper roll is removed with a velveteen covered board and graded by comparison with photographic standards. This procedure was essentially followed in the work reported here except that a range of specimen weights was used. The webs were graded to the nearest 1/3 grade, using the photographic standards supplied with the instrument. In addition, the neps per grain were determined by counting the neps and weighing the web on a microbalance. Nep counting was facilitated by substituting velveteen covered boards measuring 4 × 9 in. for the recommended 6 × 10-in. size and using the nep-counting template developed at North Carolina State College [1].

Fineness and length characteristics of the cottons were determined by means of the Micronaire and Fibrograph.

Except for some exploratory studies, all tests were performed in the standard textile testing atmosphere of 65% relative humidity at 70° F.

Exploratory Tests with Prototype

The original instrument built at North Carolina State College was used for exploratory tests on a wide variety of cottons, ranging from fine long staple to very coarse short staple cottons. Although the general appearance of the webs appeared to be in line with expectations based on fiber properties, a critical examination showed the webs to differ appreciably in thickness and uniformity as well as in number of neps per unit area. On weighing, they were generally heavier than those obtained from mill cards. These differences in web uniformity might not be of grave concern for qualitative checks of similar cottons which produced approximately the same weight webs; but for comparisons of different cottons by means of appearance standards, and for a standard laboratory test, comparable webs would be a prerequisite.

Further studies of the prototype indicated a strong linear relationship between specimen weight and web weight. The atmospheric conditions during testing also affected nep formation in most cottons, the lower humidities favoring heavier webs and fewer neps.

Tests and Results with Commercial Model

Soon after the Nepotometer was put into commercial production, one of the new models was made available for further studies on the factors affecting test results. To establish uniformity of results with the new instruments in the three laboratories, the Kendall Mills, the School of Textiles of North Carolina State College, and the Southern Regional Research Laboratory cooperated in an interlaboratory check test. All instruments and graders were found to be consistent in ranking the cottons.

A study was then undertaken with cottons ranging in Micronaire readings from 3.3 to 5.2, with corresponding upper half mean lengths ranging from 1.44 to 0.94 in., to determine the effect of specimen weight on the web weight and on the number of neps per grain. The specimen weights covered the range from 17.5 to 27.5 gr. inclusive.

These cottons with their length, fineness, and maturity values are listed in Table I along with the web weights and the log of neps per grain obtained for the different specimen weights. Auxiliary work has shown that neps per grain are best treated as the log of neps per grain. For all the cottons, both the web weight and the log of neps per grain increased with increase in specimen weight, the increases being linear with no indication of curvilinearity. Similar relationships were observed when the webs were graded against the photographic standards, a difference of about 0.3 in the log of neps per grain cor-

responding to a difference of at least one grade at log values above 1.5. The finding that the number of neps per grain always increased with increase in web weight for a given cotton should serve as a warning to those grading dissimilar webs by reference to photographic standards or by other area based measures. The values in Table I represent an average of six determinations, three of which were performed on pads prepared by hand carding and three on pads prepared by use of a mechanical blender. Any differences in the two methods of preparation were small and of doubtful significance

TABLE I. Effect of Specimen Weight on Web Weight and Log (Neps/Grain) for Four Varieties of Cotton

Cotton variety, UHM,* Micronaire reading, and maturity†	Web weight (mg./36 sq. in.) (100 mg. = 1.54 gr.) Specimen weight, gr.					Log_{10} (neps/grain) Specimen weight, gr.				
	17.5	20.0	22.5	25.0	27.5	17.5	20.0	22.5	25.0	27.5
American Egyptian 1.44 in., 3.3, 89%	111	128	146	169	200	1.59 (39)‡	1.66 (46)	1.80 (63)	1.87 (74)	1.99 (99)
Pima S-1 1.32 in., 4.1, 94%	132	155	178	203	213	1.18 (15)	1.25 (18)	1.36 (23)	1.52 (33)	1.62 (42)
Bobshaw 1.16 in., 4.8, 89%	170	202	231	260	283	0.85 (7)	1.01 (10)	1.13 (14)	1.26 (18)	1.40 (25)
Rowden 0.94 in., 5.2, 92%	172	198	229	264	291	1.03 (11)	1.13 (14)	1.21 (16)	1.27 (19)	1.38 (24)

* Upper half mean, measured with Fibrograph.
† Sodium hydroxide array method.
‡ Numbers in parentheses are corresponding numbers of neps/grain, rounded off to nearest whole number.

TABLE II. Effect of Fiber Length and Specimen Weight on Web Weight and Log (Neps/Grain) for Four Varieties of Cotton

Cotton variety, UHM,* Micronaire reading, and maturity†	Web weight (mg./36 sq. in.) (100 mg. = 1.54 gr.) Specimen weight, gr.					Log_{10} (neps/grain) Specimen weight, gr.				
	17.5	20.0	22.5	25.0	27.5	17.5	20.0	22.5	25.0	27.5
Uncut										
Seaberry Sea Island 1.54 in., 3.1, 75%	134	158	195	216	243	2.33 (212)**	2.36 (229)	2.44 (276)	2.50 (317)	2.54 (346)
Mesa Acala 1.30 in., 3.8, 88%	161	176	210	245	270	1.50 (32)	1.59 (39)	1.62 (42)	1.71 (51)	1.81 (64)
Tanguis 1.14 in., 4.6, 88%	169	193	222	240	271	0.93 (9)	1.11 (13)	1.15 (14)	1.17 (15)	1.25 (18)
Rowden 41-B 0.99 in., 5.4, 83%	195	223	242	261	292	0.79 (6)	0.84 (7)	0.95 (9)	1.00 (10)	1.03 (11)
Cut‡										
Seaberry Sea Island 0.95 in.	182	207	240	262	294	2.11 (128)	2.13 (134)	2.21 (163)	2.29 (195)	2.40 (253)
Mesa Acala 0.93 in.	177	206	223	253	273	1.27 (19)	1.23 (17)	1.31 (20)	1.36 (23)	1.44 (27)
Tanguis 0.91 in.	169	206	218	247	286	0.73 (5)	0.71 (5)	0.87 (7)	0.97 (9)	0.97 (9)
Rowden 0.90 in.	152	183	211	242	256	0.43 (3)	0.60 (4)	0.43 (3)	0.68 (5)	0.67 (5)

* Upper half mean, measured with Fibrograph.
† Sodium hydroxide array method.
‡ All varieties were cut to 1-in. lengths except Rowden 41-B, which was cut to a $1\frac{3}{32}$-in. length.
** Numbers in parentheses are corresponding numbers of neps/grain, rounded off to nearest whole number.

statistically, so the two sets of data were pooled for this analysis. In subsequent work, only hand carding preparation was used because of its greater practical importance.

The effect of specimen weight was also studied on four additional varieties of cottons having all properties essentially similar except fineness and length in the natural state and fineness alone in the cut state. These cottons represented extremes in Micronaire readings varying from 3.1 to 5.4. They had been subjected to a special cutting technique to control the length factor (see Table II) for use in an earlier investigation [5], so that the separate effects of length and fineness could be observed. The data in Table II show the same previously observed trends of increasing web weights and log of neps per grain with increasing specimen weight. Again, the relationships are linear in the region tested (17.5–27.5 gr.), with no indication of curvilinearity, for all four varieties in both the natural and cut lengths. But there are marked differences among the cottons in both web weight and in log of neps per grain for the different specimen weights.

When the values for the log of neps per grain for a constant web weight are plotted against the Micronaire readings (Figure 2), the cut cottons have uniformly less neps than the control. These curves illustrate the independent influences of length and fineness. The lower curve may be considered as representing the effect of fineness when length is constant and the vertical distance between the curves as representing the effect of length when fineness is constant. Statistical analysis of this series indicates that the difference between the curves is highly significant.

Fig. 1. The Nepotometer in operation.

Since specimen weight is an important factor in controlling web weight, multiple correlations have been performed on the data obtained from six of the eight cottons described—excluding one Rowden and the American Egyptian—to determine the specimen weight to use for a fixed web weight. A weight of 200 mg./36 sq. in. was selected as the target because no difficulties were encountered in grading webs of this weight and this value was obtainable from all the varieties of cotton studied in the specimen weight range tested. The analysis indicated that the goal could be met with about equal results by use of either of the two following simple equations, one based only on Micronaire readings, the other on Fibrograph measurements:

$$\text{Specimen weight (gr.)} = 30 - (2 \times \text{Micronaire reading}) \quad (1)$$

$$= 10\,(1 + \text{upper half mean length}) \quad (2)$$

It is recognized that these equations represent oversimplification of the factors that influence web weight. However, using Equation 1 with seven normal cottons, a mean web weight of 203 mg. with a coefficient of variation of 2% was found. For the same cottons, using Equation 2, the mean weight was 202 mg. with a coefficient of variation of 3%. On applying Equation 1 to 41 cottons varying widely in maturity and other properties, the average was

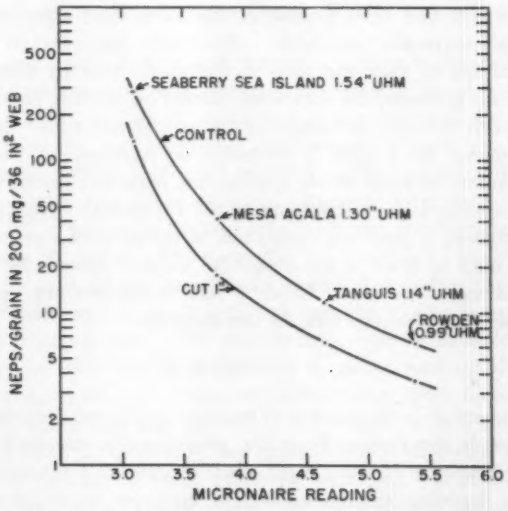

Fig. 2. The effect of Micronaire reading and upper half mean length on log (neps/grain) in 200 mg./36 sq. in. of web.

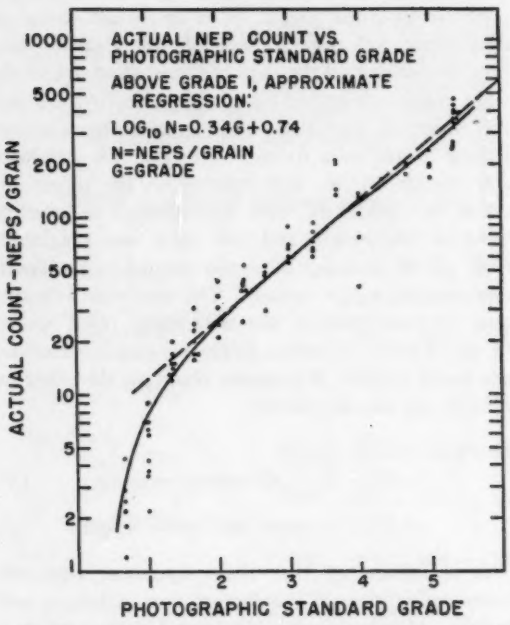

Fig. 3. Nep count in webs weighing approximately 200 mg./36 sq. in. vs. photographic standard grades.

199 with a coefficient of variation of approximately 7%.

In the course of these tests, a considerable amount of neps per grain data was accumulated on webs weighing approximately 200 mg./36 sq. in. and which had been graded at the same time with the photographic standards. To check the operator's ability to rank the webs in the same order by these two methods, the data were plotted on semilog paper with the neps per grain on the logarithmic scale. As shown in Figure 3, virtually no overlapping was found between whole grades, but considerable overlapping was observed among the 1/3 grades. Nevertheless, a good regression line in the form of a curve could be fitted to the data. Its shape is essentially a straight line above Grade 1 and in the straight line section is represented by the equation

$$\log N = 0.34G + 0.74$$

where N is the number of neps per grain and G is the grade determined from the photographic standards. Except for Grade 1, each grade represents essentially a doubling of the number of neps per grain over the preceding one. The first grade, however, appears more properly to be Grade 0 on this scale, leaving a gap to be filled with an intermediate standard. If this were done, a linear plot would be obtained over the entire range. This observation was further confirmed when an attempt was made to count the neps on the photographic standards, where a similar doubling was observed above Grade 1. Again, Grade 1 appeared to be more nearly two grades below Grade 2.

Conclusion

In conclusion, it has been shown that in the Nepotometer test as generally conducted, a standard-weight specimen does not necessarily produce a standard-weight web; there may be considerable differences in this respect among different cottons. For each of eight cottons tested, the web weight and the log of neps per grain increased with increase in specimen weight in the region tested between 17.5 and 27.5 gr. inclusive, the increases being linear with no indication of curvilinearity. Since evaluations are based on comparison of the webs with appearance standards, the production of a constant weight web in a standard test is believed to be necessary. The possibility of controlling web weight by consideration of some readily determined property such as Micronaire reading or Fibrograph upper half mean length, or a combination of these, appears promising. Two simple equations have been derived for determining the specimen weight to use for a fixed web weight—one based on Micronaire reading and the other on upper half mean length.

Statistical analysis of the data on the eight cottons indicates that simple measurements such as Micronaire reading or upper half mean length will account for about 70% of the variance in the log of neps per grain. The special need for an instrument such as the Nepotometer is for detecting those cottons with anomalous behavior that might prove troublesome in processing.

It has also been shown that neppiness standards following a regular progression can be obtained from the present photographic grades by adding another grade between the present Grades 1 and 2.

Although no positive recommendations for change in the original test procedure are being made at this time, it is hoped that users of the Nepotometer will consider the philosophy of having a fixed web weight and will try out the formulas proposed for obtaining this end.

Further studies are in progress on over 40 cottons to check the relationships reported here, to determine the reproducibility of the results obtained by the same and by different operators, and to determine the correlation between webs produced by the Nepotometer and by the carding machines in the mill.

Acknowledgments

Acknowledgment is due many members of the Laboratory staff who have contributed to these studies: Janice P. Evans for exploratory tests with the prototype; Annie B. Cooper, Dorothy C. Legendre, and Marilyn M. Smith for fiber data; E. Fred Schultz, Jr., assisted by Lorraine Leitz and Audrey Castillon, for some of the statistical analyses; McLean George for check tests with the new Nepotometer; and George Pittman for preparation of drawings.

We wish to thank particularly the Wright Manufacturing Company for providing one of the new models of the Nepotometer for use in these studies.

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Nepotometer Studies: Use as a Mill Instrument[1]

A Progress Report

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THIS report consists essentially of two parts. In the first section are presented the results of three mill experiments in which the Nepotometer grade of the cotton used was controlled. The number of neps per 100 sq. in. of card web was counted, yarn imperfections were measured on the Neptel instrument, and yarn appearance grades were determined. Changes in neps, imperfections, and yarn appearance correspond with changes in the Nepotometer grade of the raw cotton. Therefore, it is concluded that the Nepotometer does predict the tendency of cottons to form neps during processing.

In the second section is presented a comparison of the nepping potential of raw cotton, expressed as Nepotometer grade, with the conventional measurements for fineness and maturity. It is found that when attention is restricted to American Upland cottons of $1\frac{1}{32}$–$1\frac{1}{16}$ in. staple and grades of Strict Low Middling to Middling, Nepotometer grade is a vastly superior criterion to either fineness or maturity in predicting the tendency of cottons to form neps.

The testing procedure used with the Nepotometer was essentially that suggested by Professor Bogdan [2]. A 25-gr. sample of blended fibers was hand carded into a small pad, fed into the machine, and run for 4 min. The photographic standards which came with the machine were used for grading the webs produced. These standards range from Grade 1, which has very few neps, to Grade 5, with a predominance of neps. Nep grades can be estimated to the nearest one-half grade or better, as was determined by a "round robin" test between the laboratories of the North Carolina State College, the South-

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 12, 1958.

ern Utilization Research and Development Division of The United States Department of Agriculture, and The Kendall Company.

Each lot in the mill tests consisted of several bales which had been selected to possess as closely as possible identical physical properties, including grade and staple, but varying in Nepotometer grade. At the time of opening, four samples were taken at various locations throughout the bale and the Nepotometer measurements repeated to be certain of the actual cotton run. Duplicate determinations were made on each of the samples so obtained.

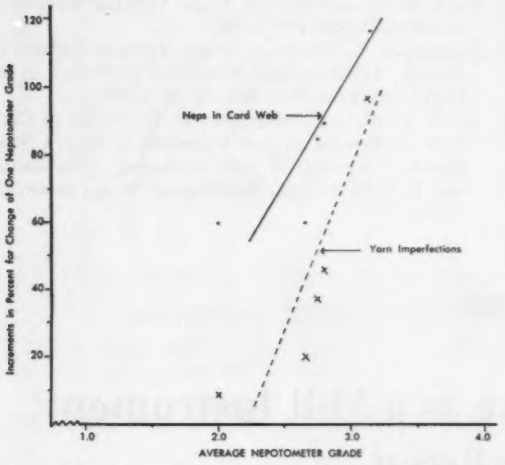

Fig. 1. Increments in neps per 100 sq. in. of card web and imperfections per 50 yd. of yarn expressed as percent for a unit increase in Nepotometer grade.

The tests reported here were conducted at different mills, each having substantially different quality requirements, and hence each with different levels of cotton quality and levels of neps in the card web. In Table I, which summarizes the essential information, the number of neps per 100 sq. in. of card web and the number of imperfections per 50 yd. of yarn are, therefore, reduced to a comparison on a 100% basis. The number of neps and imperfections for the lot in each mill test with the lowest Nepotometer grade is shown as 100%. In several instances, samples of cotton taken from the bales in the opening room were also sent to the USDA Fiber and Spinning Laboratories.

In the first test (Table I) the operation of a four bale mix having a Nepotometer grade of 1.5 is compared with a regular mix which averaged 2.5. The test card web contained little more than half as many neps; imperfections in the yarn were reduced only slightly.

In the second test two lots of five bales each were run having average nep potential grades of 2.0 and 3.5. In this instance for an increase in Nepotometer grade of 1.5, neps in the card web and imperfections increased substantially; yarn appearance decreased approximately one full grade.

In the third mill test three lots of five bales each were run. Blended samples from each lot were also

TABLE I. Neps in Card Web, Yarn Imperfections, and Yarn Appearance Grades for Three Mill Tests on Lots of Cotton with Varying Nepotometer Grades

	Test 1		Test 2		Test 3		
	Test cotton	Regular mix	Lot 1	Lot 2	Lot 1	Lot 2	Lot 3
Nepotometer grade							
Blended bale samples	1.5	2.5	2.0	3.5	2.3	3.0	3.3
Picker lap	—	—	2.0	3.5	2.3	3.3	3.7
Neps in card web/100 sq. in.							
Kendall	100%	161%	100%	212%	100%	125%	178%
USDA	—	—	100%	244%	100%	156%	200%
Yarn imperfections/50 yd.— Neptel instrument							
Kendall 30's	100%	112%	100%	184%	100%	114%	161%
Kendall 38's	100%	105%	—	—	—	—	—
USDA 22's	—	—	100%	125%	100%	113%	131%
Yarn appearance grades							
USDA 22's	—	—	B+	C+	B+	B	B
USDA 36's	—	—	B	C+	B	C+	C+

processed at the USDA Spinning Laboratory. The Nepotometer grades were 2.3, 3.0, and 3.3. Nep potential measurements made on the picker lap samples showed that there is an increased tendency to nep on the part of cottons with higher nep potentials, as the corresponding values were 2.3, 3.3, and 3.7. Neps in the card web and yarn imperfections increased substantially in the yarns produced both at the mill and those at the USDA Laboratory. Yarn appearance was lowered by about one-half grade.

There are five comparable pairs of observations within these three experiments, each having a different average nep potential (2.00, 2.65, 2.75, 2.80, and 3.15). The increments between lots, that is, the difference between nep potential grades for the individual lots, were different in each case. These may be reduced to the expected change in number of neps per 100 sq. in. of card web and that of the number of imperfections in 50 yd. of yarn for a change of one full Nepotometer grade at each of these average levels. This information is shown in Figure 1.

The data are inadequate to warrant quantitative conclusions; nevertheless they are sufficient to permit some inference regarding the probable response of yarn quality to nep potential. At low levels of nep potential, that is, in the neighborhood of Grade 2 and below, a unit variation in nep potential would not produce as big an effect on yarn quality as a unit change at a higher level, in the neighborhood of Grade 3 or higher. Therefore, the higher the Nepotometer grade the greater the increment of neps in the card web and yarn imperfections. It was found in the mills that quality differences were highly significant with a change of one Nepotometer grade, that is, from 2 to 3. The results obtained with the higher nep potential cottons exceeded the quality levels established; the change in yarn quality is apparent from the decrease in yarn appearance grade shown in the table.

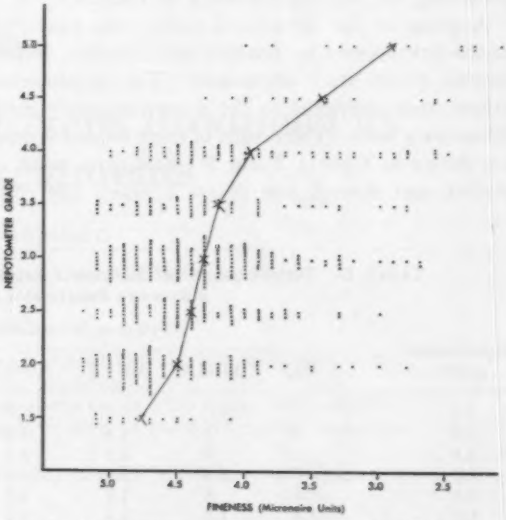

Fig. 2. Nepotometer grades vs. fineness for 527 samples of American Upland cotton.

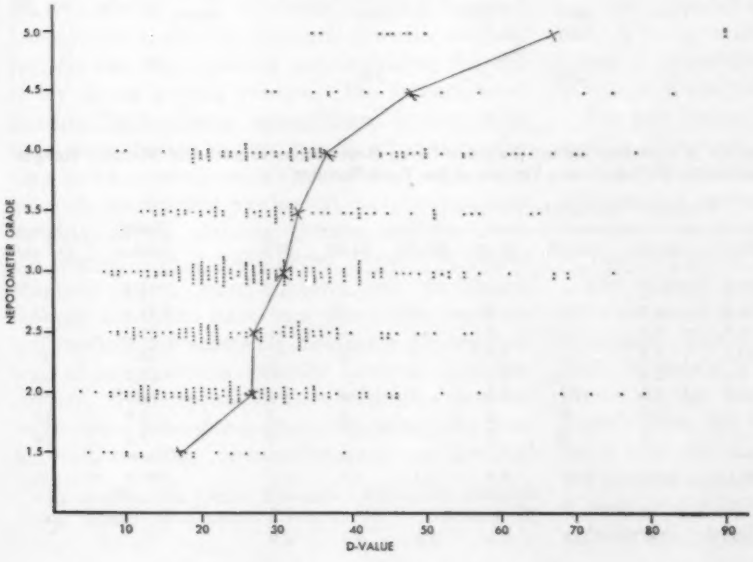

Fig. 3. Nepotometer grade vs. D-value for 527 samples of American Upland cotton.

Although the range in Nepotometer grade was small (from 1.5 to 3.5), these tests have shown that the Nepotometer can distinguish among cottons as to their nepping tendency in the mill and does provide a measure which can be used by the mills to control neps.

It is of importance to view this problem of neps briefly with reference to fineness and maturity, which have been generally accepted as broad criteria for predicting the nepping tendency of cottons.

A group of 527 samples of cotton was measured on the Arealometer for fineness and maturity; Nepotometer grades were determined. The Arealometer values were converted to the more commonly used Micronaire units. The results of these measurements are shown in Figures 2 and 3. Each data point is plotted, and through the points a heavy line connects the centers of gravity, that is, the average value of each of the distribution of data points for each of the Nepotometer grades plotted. The feature to be noted is that the Nepotometer grade is relatively insensitive to changes in either fineness or maturity in the range of nep grades between 2 and 4, as can be seen by the wide spread of data points. This wide scatter of points around the average line is quite similar to the corresponding center portion of the plot of neps in card web versus fineness shown by Dr. Earl Berkley [1]. The same information concerning fineness and D-value versus Nepotometer grade as shown in the graphs is presented in tabular form on a percentage basis in Tables II and III. Again it can be seen that the center portions of the tables are quite insensitive to changes in Nepotometer grade.

TABLE II. Distribution of 527 Samples of American Upland Cotton in Given Nepotometer Grades and Micronaire Ranges as a Percent of the Total Number

Nepotometer grade	Fineness, Micronaire units						Total percent	Mean fineness value
	<3.0	3.0–3.5	3.5–4.0	4.0–4.5	4.5–5.0	5.0>		
1.5	—	—	—	.3	1.5	1.0	2.8	4.8
2.0	.2	.5	1.5	5.5	9.9	3.4	21.1	4.5
2.5	—	.6	2.1	5.3	8.0	1.5	17.4	4.4
3.0	.7	1.5	3.4	10.4	9.3	3.0	28.5	4.3
3.5	.6	.8	1.7	4.0	3.2	1.1	11.4	4.2
4.0	1.7	1.5	2.3	4.2	3.6	.4	13.7	4.0
4.5	.8	.6	.8	.8	—	—	2.8	3.4
5.0	1.3	.6	.2	.2	—	—	2.3	2.9
Total percent	5.3	6.1	12.0	30.7	35.5	10.4	100.0	
Mean Nepotometer grade	4.1	3.5	3.2	3.0	2.7	2.6		

TABLE III. Distribution of 527 Samples of American Upland Cotton in Given Nepotometer Grades and Maturity Ranges (Arealometer D-Value) as a Percent of the Total Number

Nepotometer grade	Maturity, Arealometer D-value									Total percent	Mean D-value
	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80>		
1.5	.6	1.3	.8	.2	—	—	—	—	—	2.8	17
2.0	.9	6.2	6.6	4.5	1.5	.4	.2	.5	—	21.1	27
2.5	.6	4.2	5.7	5.1	1.3	.6	—	—	—	17.4	27
3.0	.9	4.4	10.1	7.2	3.4	1.5	.8	.2	—	28.5	31
3.5	—	2.3	3.0	3.0	1.5	1.1	.4	—	—	11.4	33
4.0	.2	1.1	4.0	3.8	1.7	1.3	.9	.6	—	13.6	37
4.5	—	—	.2	1.0	.8	.4	—	.4	.2	2.9	48
5.0	—	—	—	.4	.8	.2	—	—	.9	2.3	70
Total percent	3.2	19.5	30.4	25.2	11.0	5.5	2.3	1.7	1.1	100.0	
Mean Nepotometer grade	2.4	2.6	2.8	3.0	3.3	3.4	3.4	3.3	4.9		

From the graphs and corresponding tables it can be seen that there is no doubt regarding the existence of the general trend for the finer and more immature cottons to produce more neps than the coarser and more mature ones. However, for the commercial grades of American Upland cottons in the normal range of fineness and maturity, fineness and maturity are totally inadequate criteria to effect a satisfactory control of neps. The Nepotometer does fill this gap and provides a means for estimating nep performance of cottons in the mill.

Literature Cited

1. Berkley, Earl E., Marth, Charles T., and Arthur, Harry E., TEXTILE RESEARCH JOURNAL **22**, 561–566 (1952).
2. Bogdan, J. F., TEXTILE RESEARCH JOURNAL **24**, 491–495 (1954).

Means for Measuring Neps Produced by Ginning Treatments[1]

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Abstract

A faster method of measuring neps in cotton ginned lint has been developed at the Cotton Ginning Research Laboratory, Stoneville, Mississippi.

The time saved by this method is due largely to the use of a lap maker and a modified definition of what constitutes a nep, and amounts to 50% of the AMS method currently used.

This method is used at the Stoneville Laboratory to make preliminary screening tests in the Ginning Research program.

RESEARCH at U. S. Cotton Ginning Research Laboratories is directed in general towards maintaining inherent fiber qualities and increasing the efficiency of the ginning process. The author's work involves the laboratory measurement of fiber properties at Stoneville as they may be affected by ginning and associated operations. For example, it is generally known that mechanical operations such as handling, drying, cleaning, ginning, and lint cleaning produce neps in cotton fiber. These fiber tangles adversely affect yarn quality, and considerable thought and effort have been devoted to machines and methods for accurately measuring the nep content of samples from different processes and machinery. Two procedures were studied; a modified nepotometer method was selected to prepare the webs for visual counting. In counting, a nep was identified as a tightly tangled mass of lint cotton fiber not larger than $\frac{1}{16}$ in. or smaller than $\frac{1}{64}$ in. in diameter consisting of several fibers tangled or knotted sufficiently to appear as one mass to the naked eye.

The new method for measuring neps produced by ginning treatments shows promise in reducing the time required in making nep counts in connection with ginning research. Much more testing will be necessary, however, before the new method can be used in place of well established methods.

The original nepotometer method of nep determination requires 25 gr. of lint fiber from the lot to be tested. This fiber is carded between two hand cards to make a 5 × 5-in. pad or lap, which is then placed on the feed table of the nepotometer and tucked under the feed roll. After the timer is set for 4 min., the machine is started. At the end of the running time, the presser plate is removed and a piece of 6 × 10-in. cardboard covered with black velveteen is placed in contact with the web at the

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 12, 1958.

back of the top roll. By maintaining contact with the web as the board is swung forward, the web is made to adhere to the pile of the velveteen. The sample web is broken at the edge by swinging the board away from the roll. The appearance of the web is compared for neppiness against a set of five standard photographs which show a range of neps from very low to very high.

A second method developed and used by the Agricultural Marketing Service involves the use of a fiber blender and small card or nep test machine. A 3-g. sample is blended and then fed into the nep test machine to form a web similar to the card web produced by a commercial card. As soon as the web is delivered from the doffing comb, it is picked up by hand; as it is being delivered, a section is laid on a 4 × 9-in. board covered with black velvet. Nine subsequent sections are taken in the same way on black velvet boards. The ten web specimens are counted by two technicians and averaged. From the average count, the number of neps per 100 sq. in. is calculated.

The Stoneville Method

The Stoneville method consists of pinching and weighing the test specimen, making lap for the nepotometer, preparing the web by using the nepotometer, and visually counting the neps in the web.

In order to eliminate variation in the preparation of the lap by hand carding and to speed up the operation, thought and consideration was given to "mechanizing" this part of the procedure. After making a study of fiber blenders and small cards, a small lap-making machine was designed and built at the Stoneville Cotton Ginning Laboratory to replace the hand cards furnished with the nepotometer.

Test Procedure

The sample to be tested is spread out so that 10 pinches of about 2 gr. each can be taken at random. Each pinch is pulled out into a strand 6 in. long, and all are placed side by side to form a bat approximately 5 in. wide.

This machine consists of a 6-in. card cylinder, a 3-in. doffing cylinder, a feed roll, and feed plate. Final operating conditions selected are a feed roll speed of 1.92 r.p.m., a card cylinder speed of 92 r.p.m., and a doffing cylinder speed of 265 r.p.m., with a feed roll setting of $\frac{1}{32}$ in. from the card cylinder; the doffer teeth are set $\frac{1}{16}$ in. into the card cylinder teeth. Results from these settings were found to be comparable with results obtained on the small nep test machine developed and used by AMS.

The Stoneville lap maker is started after placing the handmade bat of 10 strands on the feed table. The machine is allowed to run until all the bat is fed into the 6-in. card cylinder and the doffing cylinder has removed all the fiber from the card cylinder, after which the lap is removed from the doffing cylinder by hand. A small pointed rod 10 in. in length is placed under the fibers through the doffer teeth and then raised up and out to break the lap.

The lap then can be removed by rotating the doffer cylinder backward with one hand and grasping one end of the broken lap with the other hand, at the same time lifting the mass of fibers or lap as the cylinder is turned. The lap is then placed on the nepotometer feed table and, after the timing device is set for $3\frac{1}{2}$ min., the machine is started. A flat piece of plastic or other suitable material is used to start the lap feeding. When the machine stops, one-third of the web about 6 in. long is removed from the top and stretched over 4 × 9-in. glass. A 4 × 9-in. template with three 1 × 8-in. openings is placed over the web and the neps or tangles counted by two technicians. Each of the remaining thirds of the web is removed and treated in the same manner. The average count multiplied by 36/24 or 1.5 and divided by the weight of the web in grains is the nep count in neps per grain.

Table I shows the steps involved in each of the three methods described.

Counting neps visually in cotton fibers is quite difficult. What constitutes a nep is largely dependent on the operator, since size and tightness of the fiber entanglement must be considered. In order that different operators improve their agreement in counts on the same webs, the nep characteristics were studied. It was agreed after considerable experience in visual nep counting by myself and associates to limit or change the definition of a nep from "one or more fibers occurring in a tangled and unorganized mass" (American Society of Testing Materials) to "a tightly tangled mass of lint cotton fibers not larger than $\frac{1}{16}$ in. or smaller than $\frac{1}{64}$ in. in diameter consisting of several fibers tangled or knotted sufficiently to appear as one mass to the naked eye." Counts were made using both the conventional and our own definition or method of recognizing a nep visually (Table II).

The original nepotometer method was not a suit-

able measure of neps in our samples due to the large amount of time required for hand preparation of the bats and the wide latitude of the grades or standards for evaluation of the neppiness. For these reasons an improved method was sought plus a method that provided a numerical value of neppiness so that finer differences could be measured.

The AMS method previously described provides such a method giving fine differences but at a rate of only four samples per hour. Eight samples per hour can be processed by the Stoneville method. Most of the differences in the time needed to make tests employing these two methods is accounted for in the time used for visual counting. The nature of the ginning research work necessitates a large number of nep evaluations—so many, in fact, that a faster method than the AMS method was needed.

It should be noted that the number of neps per grain (Stoneville method) is slightly more than are found in 100 sq. in. of web (approximately 3 gr.) using the AMS small nep machine procedure. The reason this magnified count was needed was to measure the nep count in samples which had only slight changes in gin treatment and to obtain a more accurate determination.

Use of Stoneville Method

An example of using the Stoneville method of nep counting may be illustrated by a ginning test performed at Stoneville in 1955. To spin samples from all the test lots was prohibitively expensive. We desired to select test lots for further testing on a basis of preliminary information that showed the further expenditure of funds would be warranted.

Each test lot was dried in a 17-shelf tower drier with 225° F. being maximum temperature to which cotton was exposed; it was ginned on a standard 80-saw stand. The quantity of seed cotton cleaning machinery used in the test varied from none to 20 cylinders of screen cleaning plus bur machine and extractor-feeder.

TABLE I. Comparison of the Test Operations in Three Nep Test Methods

Step	Test method		
	Original nepotometer	AMS nep test machine	Stoneville nepotometer
Pinching and weighing	X**	X	X
Hand carding	X	None	None
Blending	None	X	None
Carding	None	X	None
Lap maker	None	None	X
Nepotometer	X	None	X
Counting:			
Comparison to standard	X	None	None
Ten 4×9-in. boards* (360 sq. in.)	None	X	None
Three 4×9-in. boards* (72 sq. in.)	None	None	X

* By two operators.
** X indicates step was used.

TABLE II. Comparison of Visual Nep Counting Using Two Definitions of a Nep

Sample no.	ASTM definition	Stoneville definition
	Neps/gr.	Neps/gr.
1	18	7
2	26	11
3	56	18
4	64	19
5	64	19

TABLE III. Neps in Samples from Cotton Cleaned by Eight Combinations of Gin Machinery and Measured by Stoneville and AMS Nep Test Methods

Sample identification	Machinery used	Stoneville method, nepotometer	AMS method
		Neps/gr.	Neps/100 sq. in.
1	Hand fed to gin stand by-passing huller front	15	9
2	Hand fed to gin stand* through huller front	21	12
3	Extractor-feeder to gin stand, normal feed	18	13
4	7-cylinder cleaner, extractor-feeder	12	13
5	6-cylinder cleaner, master bur extractor, extractor-feeder	18	11
6	13-cylinder cleaning extractor-feeder	15	9
7	13-cylinder cleaning, master bur extractor, extractor-feeder†	15	14
8	20-cylinder cleaning, extractor-feeder‡	27	16

* Standard gin feeding through the huller front was used in all test lots except Lot 1.

† Sequence was 6-cylinder cleaner, bur machine, 7-cylinder cleaner.

‡ Sequence was 7-cylinder cleaner, 6-cylinder cleaner, 7-cylinder cleaner.

The expected result in Table III is for the number of neps to progressively increase from Sample 1 through Sample 8, because more cleaning machinery was added on each succeeding setup. Neither the Stoneville method nor the AMS method shows this conclusively; however, essentially the same pattern may be found from either method. To us it was important that this pattern could be derived by the Stoneville method in only $\frac{1}{2}$ the time required by the AMS method.

The Stoneville nepotometer test is a valuable measure for screening tests on lint cotton lots in our ginning projects. In this manner it is determined which lots should be subjected to spinning tests. As a result, considerable time and money are saved in our fiber and spinning test program.

Laboratory Evaluation of Nep Potential[1]

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NEP control plays an important role in the quality control program of most cotton mills. Counting neps in the card web has been used as an effective method of controlling neps because the cards influence nep removal more than any other process [3]. The nep removal efficiency of the cards depends not only on the neppiness of the laps but mainly on the mechanical condition of the cards.

Most mills wish to avoid cotton that will produce a high nep count. Efforts to find causes of neppiness and methods of reducing neps have produced considerable information on this subject [1]. The effects of ginning [4] and mill processing conditions [2] have been related to neppiness in cotton cloth. Since there are so many properties which affect the nep potential, an instrument that simulates processing is needed to reflect the combined effect of all the properties. The Nepotometer is an instrument designed for this purpose.[2]

The work of this laboratory has been directed toward determining the usefulness of the Nepotometer for plant cotton buyers and blenders.

Experimental Method

All tests on the Nepotometer were made according to manufacturer's directions. The running time was

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, North Carolina, February 12, 1958.

[2] Developed by School of Textiles, North Carolina State College; manufactured by Wright Machinery Co., Durham, N. C. (subsidiary of The Sperry Corp.).

TABLE I. Nepotometer: Reproducibility Tests—Six Tests per Bale Sample

	$\frac{31}{32}$ in. SGO		1 in. LM		$1\frac{1}{32}$ in. SLM		$1\frac{1}{16}$ in. M	
	Nepotometer grade	Fineness	Nepotometer grade	Fineness	Nepotometer grade	Fineness	Nepotometer grade	Fineness
Test number								
1	3.5	4.2	3.0	4.2	2.5	4.2	1.5	4.6
2	3.5	4.1	3.0	4.2	2.5	4.1	1.5	4.5
3	3.5	4.2	3.0	4.1	2.5	4.2	1.5	4.6
4	3.5	4.2	3.0	4.2	2.5	4.2	1.5	4.6
5	3.5	4.1	3.0	4.3	2.5	4.1	1.5	4.5
6	3.5	4.1	3.0	4.2	2.5	4.3	1.5	4.5
Average	3.5	4.15	3.0	4.2	2.5	4.18	1.5	4.55
Range	0	0.1	0	0.2	0	0.2	0	0.1

4 min., the sample weight 25 gr. The samples were distributed evenly on one hand card with no further carding. Special care was taken to make even pads or laps and to feed them evenly. It is evident that consistent sample preparation is necessary for reproducible results.

All results of Nepotometer tests were compared to the Nep Standards (Tentative) photographs for grading, which classify the web in grades I, II, III, IV, and V. Since many webs appeared to be between the standard grades, results have been recorded to the nearest half grade.

Results

Reproducibility of Test

Results of six Nepotometer tests per bale on four grades of cotton are given in Table I. The same Nepotometer grade for each sample on the same bale indicated good reproducibility of test results.

Relation of Fineness to Nepotometer Grade

Four cotton samples were tested at each micronaire fineness reading from 3.0 to 5.5 (only two samples were available at each reading above 5.2). Two series of tests were made on these samples. In general, finer cotton showed higher nep potential, coarser cotton lower nep potential (Figure 1). The range of grades (shown by dots above and below average reading) indicates that apparently there are factors other than fineness which affect nep potential.

For example, one sample at 3.1 fineness had a Nepotometer grade of 2.5, which is no higher than some of the samples at 4.3–4.8 fineness. This means that fine cottons may be used as low as 3.0 fineness to improve strength, provided the Nepotometer grade is 2.5 or lower. These fine cottons may be used for added yarn strength qualities with little or no increase in neppiness.

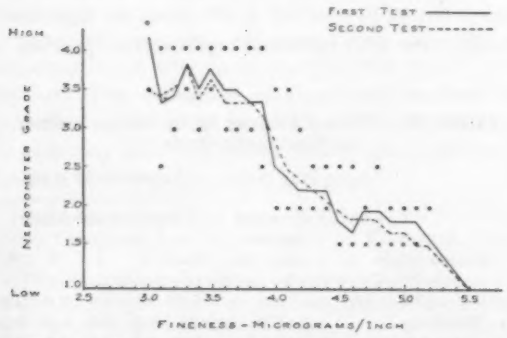

Fig. 1. Nepotometer grade compared with fineness; $1\frac{1}{32}$-in. SLM cotton.

Predicting Nep Formation

Tables II and III show Nepotometer grade on cotton from two mills at various stages in processing compared with the Cone Mills Laboratory method of

TABLE II. Effect of Processing on Nepotometer Grade and Nep Count

Grade: blend of Low Middling and Strict Low Middling
Staple: $1–1\frac{1}{16}$ in.

	Nepotometer grade	Neps/gr.	Fineness
Blend of bale cotton	2.5	15	4.2
Cotton delivered from each machine in opening line			
No. 12 opener	2.5	19	4.2
Vertical opener	2.5	21	4.0
Second vertical opener	2.5	20	4.1
Cotton delivered from each section of pickers			
Breaker section	2.5	21	3.9
Intermediate section	3.0	21	3.9
Finisher section	3.5	23	4.0
Card sliver	1.5	11	4.3
Drawing sliver	1.5	12	4.4
Slubber roving	1.5	13	—

TABLE III. Effect of Processing on Nepotometer Grade and Nep Count

Grade: blend of Low Middling and Strict Low Middling
Staple: $1–1\frac{1}{16}$ in.

	Nepotometer grade	Neps/gr.	Fineness
Blend of bale cotton	2.0	13	4.4
Cotton delivered from each machine in opening line			
Vertical opener	3.0	14	4.4
No. 11 condenser over No. 12 opener	2.5	15	4.5
Second vertical opener	3.0	13	4.4
Superior cleaner	3.0	16	4.5
Cotton delivered from each section of pickers			
Breaker section	3.0	15	4.4
Intermediate section	3.0	19	4.4
Finisher section (lap)	3.0	21	4.6
Card sliver	1.5	10	4.5
Drawing sliver	1.5	11	4.8
Slubber roving	1.5	12	—

counting neps. These results denote that the Nepotometer can be used to determine whether one blend has more nep potential than another. However, it does not predict nep formation qualities due to processing factors. These processing factors appear to be more important in forming and removing neps than the nep potential of the original blend.

TABLE IV. Effect of Carding on Nepotometer Grade and Nep Count

	Card number				
	1	2	3	4	5
Neps/gr. in lap sample	24	27	23	20	25
Nepotometer grade of lap sample	2.5	3.0	3.5	3.0	3.0
Neps/36 sq. in. of card web	10	15	18	13	16
Nepotometer grade of card web	1.5	1.5	1.5	1.5	1.5

TABLE V. Effect of Carding on Nepotometer Grade and Nep Count

Blend of bale cotton	Blend of SGO and LM cotton carded at 16 lb./hr.		
Neps/gr.	23		
Nepotometer grade	3.5		
Card number	1	2	3
Lap			
Neps/gr.	39	32	35
Nepotometer grade	3.5	3.5	3.5
Card web			
Neps/36 sq. in.	18	24	32
Nepotometer grade	2.5	2.5	2.5
Original carded web*	1.5	2.0	2.0

* Graded by Nepotometer Standard Photographs.

TABLE VI. Effect of Carding on Nepotometer Grade and Nep Count

Blend of bale cotton	Blend of LM and SLM cotton carded at 11 lb./hr.			
Neps/gr.	18			
Nepotometer grade	2.0			
Card number	1	2	3	4
Lap				
Neps/gr.	26	30	28	27
Nepotometer grade	2.5	2.5	2.5	2.5
Card web				
Neps/36 sq. in.	6	6	12	18
Nepotometer grade	1.5	1.5	1.5	1.5
Original carded web*	1.0	1.0	1.5	1.5

* Graded by Nepotometer Standard Photographs.

The trend of the Nepotometer grade and actual nep count method through various stages of processing is similar (Tables II and III). The Nepotometer grade does not correlate too closely with Cone Mills method, though, and does not appear to be as useful in pinpointing processing stages that may be producing neppiness.

Finding Cards That Need Adjusting

The Nepotometer grade as well as nep count on card web shows that cards remove neps (Tables IV, V, and VI). There does not appear to be enough difference in Nepotometer grade from card to card to use this as a method for finding cards producing poor work. However, these results point up the fact that the control of neps must be maintained by proper adjustment of the cards for maximum nep removal efficiency.

Effect of Cleaning Cotton on Nep Potential

Tests were made by running cotton through the Shirley Analyzer to determine effect of cleaning on nep potential. Cleaning the cotton reduces the nep potential to a certain point. However, the nep potential is dependent on the grade of cotton, irrespective of fineness or cleaning (Table VII).

Conclusions

Results of these tests, in general, lead to the conclusion that the Nepotometer is a useful and helpful tool in showing nep potential of cottons and blends, but does not give sufficient information to be used for reducing nep formation qualities due to processing factors.

The principal use of this instrument would be for cotton buyers in selecting finer cottons for maximum strength but with minimum nep potential qualities.

TABLE VII. Effect of Cleaning by the Shirley Analyzer on Nepotometer Grade

Cotton grade	Fineness micro-grams/in.	Nepotometer grade: Passes through Shirley Analyzer None	1	2	3	4
Strict Good Ordinary	4.1	5.0	4.0	3.5	3.0	3.0
Low Middling	4.2	3.0	2.0	2.0	1.5	1.5
Strict Low Middling	4.0	2.0	1.5	1.0	1.0	1.0
Middling	4.5	2.0	1.5	1.5	1.0	1.0

Acknowledgment

The valuable contributions of co-workers in Cone Mills Laboratory, particularly W. N. Lilly for experimental work and Mrs. Audree D. Anthony and James P. Patton, Jr. for assistance in the preparation of this paper, are gratefully acknowledged.

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Transmission of Cotton Fiber Strength and Extensibility[1,2]

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Abstract

The breaking tenacities and breaking elongations of six experimental cottons are compared in several textile structures. These structures include single fibers, fiber Pressley bundles, yarns, and fabrics in two constructions.

It is shown that the breaking tenacity of single fibers is not fully transmitted to more complex textile structures. The degree of transmission of single fiber strength is not constant for the six cottons, but is dependent upon the breaking tenacity of the single fibers. The transmission of fiber breaking elongation to more complex textile structures also is found to vary for the six cottons and to be inversely proportional to the single fiber breaking elongation.

It is concluded that while the differences among the experimental cottons in fiber strength and extensibility are clearly evident in the textile structure properties, these differences tend to be leveled out by the textile manufacturing operations.

Introduction

Measurement of the force required to rupture cotton fibers and measurement of the extension of the fiber prior to rupture have received considerable attention in the past two decades. Cotton breaking strength and breaking elongation now are often measured in an attempt to establish the quality of the lint. The evaluation of these two mechanical properties is carried out in addition to characterizing the cotton by more established values, such as length, fineness (Micronaire), color, and grade.

Instruments, which have received wide acceptance by the cotton industry, have been devised to measure the breaking strength and elongation of cotton fiber bundles [2, 9]. Research teams have developed techniques for the measurement of the breaking force and extension, as well as other mechanical properties of single cotton fibers [5, 6, 14]. Correlation analyses between parameters obtained by single fiber methods and the more common bundle techniques indicate that essentially the same fundamental properties are being measured by these two rather divergent techniques [3, 7, 13].

It is the purpose of this paper to present the relationships between the strength and extensibility of single cotton fibers and the corresponding properties of bundles, yarns, and fabrics and to indicate the degree of transmission of single fiber properties to

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 13, 1958.

[2] This work was performed as part of the Cotton Research Project of Textile Research Institute. A portion of this work was done under contract with the U. S. Department of Agriculture and was authorized by the Research and Marketing Act.

the properties of the resultant textile structures for several experimental cotton types.

A comparison of the breaking strengths of single fibers, fiber bundles, yarns, and fabrics to indicate the transmission of strength from simple to more complex structures has been accorded only limited attention. A decrease in strength with increasing gauge length is well documented for both single fibers and fiber bundles [4, 8, 11]. However, even when the strength tests on single fibers, fiber bundles, and other more complex textile structures are conducted at a gauge length other than zero, the transmission of the strength characteristic is by no means perfect [1, 7]. While it has been shown previously that the transmission of fiber strength is not perfect, it would be of interest to determine whether or not the degree of transmission is constant for all cottons and to establish some broad principles regarding the transmission of fiber strength.

While the breaking elongation of cottons, measured either by single fiber methods or by bundle techniques, has been shown to correlate with yarn breaking elongation [3, 13], the degree of transmission of cotton extensibility to more complex textile structures has not been investigated thoroughly.

TABLE I. Experimental Breaking Strength Values

Cotton	Single fiber breaking stress, Mg./cm.²	Pressley strength, 5-mm. gauge, g./grex	Yarn breaking strength, g. 12's	21's	29's
Pima S-1	6.55	2.42	1015	595	414
Deltapine	3.54	1.34	626	405	289
Sea Island	5.10	2.03	904	518	353
Acala	4.25	1.71	744	454	312
Hybrid	6.01	2.28	1037	566	402
Lengupa	5.10	1.65	542	365	238

TABLE II. Experimental Breaking Strength Values

Cotton	Fabric breaking strength, aver. warp and fill, lb. Sheeting Scrd.	Sheeting Res. fin.	Oxford Scrd.	Oxford Res. fin.
Pima S-1	170.4	106.4	164.6	121.3
Deltapine	113.4	86.0	118.8	90.9
Sea Island	153.8	106.6	151.4	117.8
Acala	140.2	96.0	130.8	105.3
Hybrid	153.4	106.1	166.6	125.8
Lengupa	128.9	83.4	114.2	85.2

Experimental

Six cottons, representing a wide range in fiber mechanical properties, were considered in this research. The mechanical properties of fibers from these six cottons were evaluated by previously de-

TABLE III. Calculated Breaking Tenacities, g./grex

Cotton	Single fibers	Pressley bundles, 5-mm. gauge	Yarns 12's	21's	29's	Fabrics: Sheeting Scrd.	Sheeting Res. fin.	Oxford Scrd.	Oxford Res. fin.
Pima S-1	4.25	2.42	2.36	2.18	2.06	2.14	1.24	2.10	1.44
Deltapine	2.30	1.34	1.35	1.58	1.52	1.54	1.08	1.49	1.12
Sea Island	3.31	2.03	2.08	1.85	1.74	1.94	1.44	1.93	1.43
Acala	2.76	1.71	1.68	1.70	1.58	1.84	1.24	1.63	1.28
Hybrid	3.90	2.28	2.24	2.10	1.94	1.95	1.34	2.01	1.51
Lengupa	3.31	1.65	1.18	1.38	1.21	1.67	1.10	1.40	1.01

TABLE IV. Experimental Elongations to Break, %

Cotton	Single fibers	Pressley bundles, 5-mm. gauge	Yarns 12's	21's	29's	Fabrics: Sheeting Scrd.	Sheeting Res. fin.	Oxford Scrd.	Oxford Res. fin.
Pima S-1	11.0	8.5	9.4	10.4	9.0	24.6	13.8	19.8	10.8
Deltapine	6.6	5.8	7.7	8.7	7.3	18.2	11.2	16.0	8.4
Sea Island	8.8	7.4	8.6	9.0	7.8	22.6	13.2	17.4	10.4
Acala	7.9	6.9	7.8	8.1	7.0	20.0	12.0	16.4	9.8
Hybrid	6.0	5.6	7.2	7.8	6.6	20.6	12.0	17.0	9.4
Lengupa	12.4	10.5	9.9	10.2	8.6	22.2	12.8	18.0	10.2

scribed single fiber testing techniques at ½-in. gauge length [14]. Pressley bundle strength tests were performed at 5-mm. gauge spacing using the Instron tensile testing machine [12]. The six cottons were processed under identical conditions into three yarn counts (12's, 21's, and 29's), and the yarn breaking strengths and elongations were evaluated by the single-strand method. The yarns were woven into two fabric constructions (sheeting and oxford) which were available both in a scoured and in a bleached, mercerized, and resin-finished condition. The breaking strength and elongation of the fabrics were evaluated by the grab test method using the Instron tensile testing machine. Tables I and II summarize the experimental breaking strength results in the units in which these results were obtained. Table III presents the same experimental data expressed in common tenacity units (grams per grex). Table IV summarizes the experimental breaking elongation results.

Results

Strength

Figure 1 shows the relationship between the single fiber breaking tenacity and the breaking tenacity of Pressley bundles at 5-mm. gauge spacing for the six cottons under investigation. It can be observed that five of the cottons establish a clear relationship, but that the Lengupa cotton does not follow the pattern. On the basis of the breaking tenacity of single fibers, a higher bundle strength is to be expected for the Lengupa cotton.

Figure 2 shows the relationship between yarn breaking tenacity and single fiber breaking tenacity. Here again a good relationship is to be noted for five of the six experimental cottons; however, Lengupa exhibits a lower yarn strength than is to be expected on the basis of its single fiber breaking tenacity.

Figure 3 shows the relationship between single fiber breaking tenacity and fabric breaking tenacity. The fabric values represent averages over both fabric constructions in both wet finishing conditions. The relationship between fiber and fabric breaking tenacity is the same as that discussed for bundles and yarns. Five of the six cottons follow a good relationship, but the Lengupa cotton exhibits a lower fabric breaking tenacity than would be expected on the basis of its single fiber breaking tenacity.

Figure 4 shows the fiber–fabric relationships for the two fabric constructions in the scoured and resin-finished conditions.

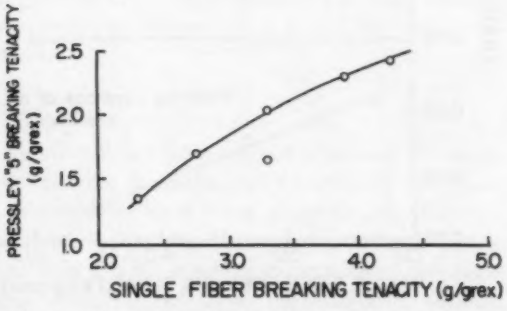

Fig. 1. Relationship between Pressley bundle and single fiber breaking tenacity.

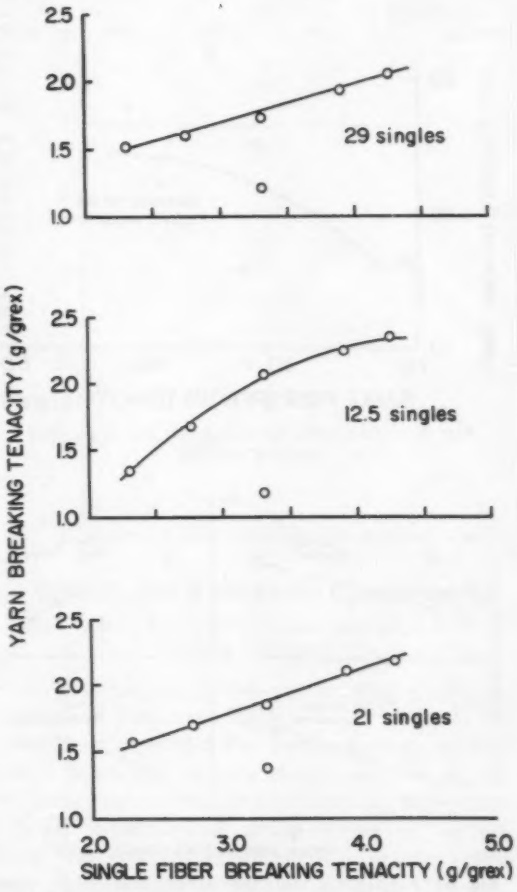

Fig. 2. Relationship between yarn and single fiber breaking tenacity.

On the basis of the relationships shown in Figures 1–4, and upon examination of the breaking tenacities listed in Table III, certain interesting observations may be made. The transmission of single fiber strength to the strength of textile structures such as bundles, yarns, and fabrics does not appear to be a perfect one. Further, the strength transmission does not appear to be constant for all cottons. In order to express this phenomenon more quantitatively let us define the "transmission coefficient" as the ratio of the breaking tenacity of the textile structure (bundle, yarn, fabric) to the breaking tenacity of the single fibers when these values are expressed in common units, such as grams per grex. Thus, a transmission coefficient of unity indicates perfect transmission of fiber strength to the bundle, yarn, or fabric under consideration. Table V presents the breaking tenacity transmission coefficients for each of the textile structures considered (bundles, yarns, and fabrics). The low transmission coefficients for fabrics are in part due to the decrease in fabric strength as a result of the resin finishing treatment [10]. A grand average transmission coefficient for all the textile structures is presented in the last column of Table V.

TABLE V. Breaking Tenacity Transmission Coefficients

Cotton	Pressley bundle, 5-mm. gauge	Yarns, aver.	Fabrics, aver.	Grand average
Pima S-1	0.57	0.52	0.41	0.50
Deltapine	0.58	0.64	0.57	0.60
Sea Island	0.61	0.57	0.51	0.56
Acala	0.62	0.60	0.54	0.59
Hybrid	0.58	0.54	0.44	0.52
Lengupa	0.50	0.38	0.39	0.42
Average	0.58	0.54	0.48	0.53

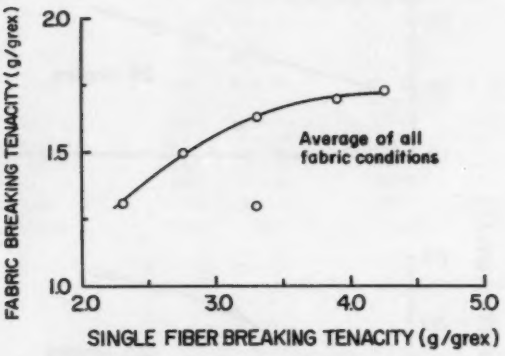

Fig. 3. Relationship between fabric and single fiber breaking tenacity.

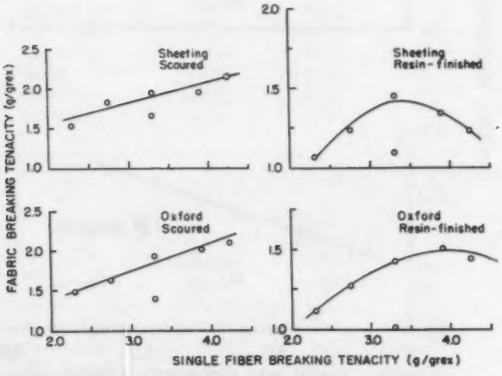

Fig. 4. Relationship between fabric and single fiber breaking tenacity. Individual fabric construction and wet-finishing condition.

The first point to be noted is that the breaking tenacity transmission coefficient is far from unity,

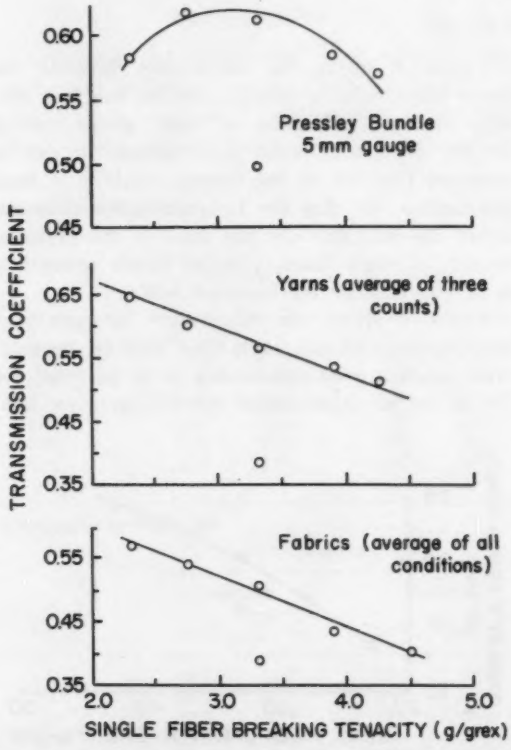
TRANSMISSION COEFFICIENT
Pressley Bundle 5 mm gauge
Yarns (average of three counts)
Fabrics (average of all conditions)
SINGLE FIBER BREAKING TENACITY (g/grex)

Fig. 5. Relationship between breaking tenacity transmission coefficient and single fiber breaking tenacity.

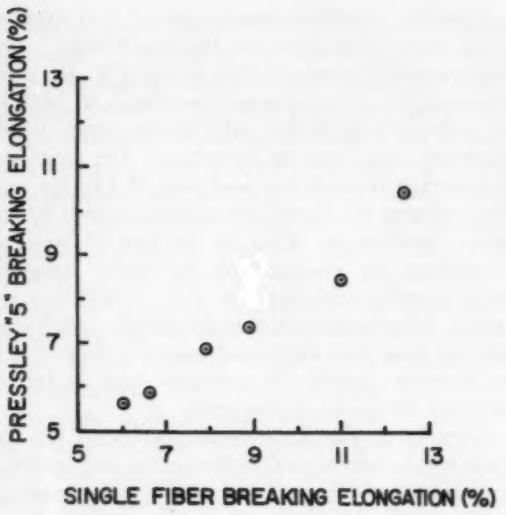

Fig. 6. Relationship between Pressley bundle and single fiber breaking elongation.

averaging about 0.53. Further, these coefficients are not constant for all cottons, but are dependent upon the original fiber breaking tenacity.

Figure 5 shows the relationship between the transmission coefficient and the single fiber breaking tenacity of the six experimental cottons under consideration. In all cases it is apparent that the transmission coefficient is a function of the fiber breaking tenacity, the weaker cottons exhibiting a higher transmission of their fiber strength. As was indicated previously, the transmission coefficients for the Lengupa cotton are significantly lower than for the remaining five cottons, and in none of the three textile structures considered does the Lengupa cotton follow the established relationship. It must be assumed that some fiber property inherently present in the Lengupa prevents the transmission of fiber strength from being as efficient as it is for the other five cottons.

Elongation

Figure 6 shows the relationship between the single fiber breaking elongation and the breaking elongation of Pressley bundles at 5-mm. gauge length. Figure 7 shows the relationship between single fiber breaking elongation and the breaking elongations of the single yarns, while Figure 8 shows the relationship between the breaking elongations of single fibers and fabrics

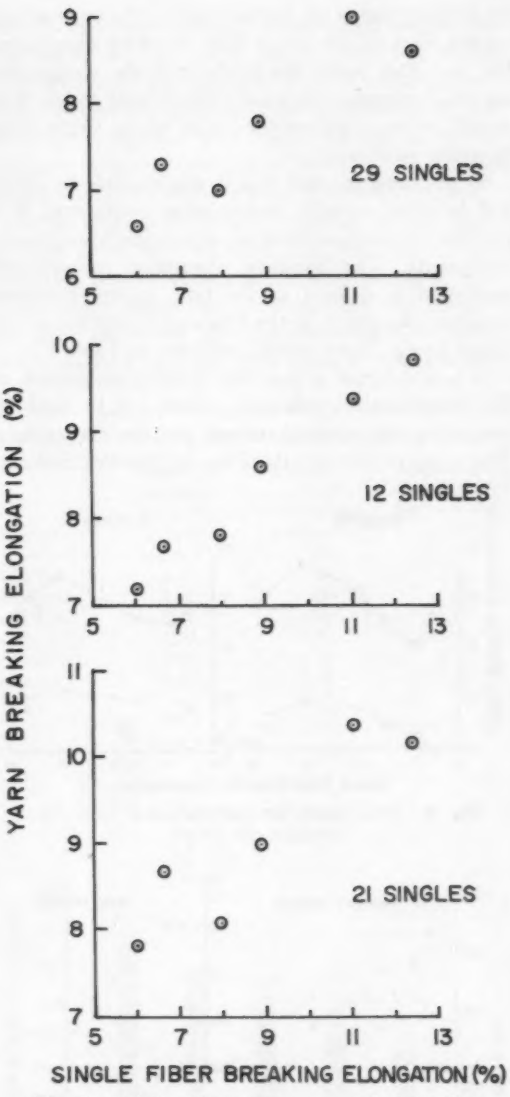

Fig. 7. Relationship between yarn and single fiber breaking elongation.

in two constructions in two wet finishing conditions (averages of warp and filling).

It will be noted that the Pressley bundle elongations to break and the yarn elongations to break are well correlated with single fiber breaking elongation. However, the fabric breaking elongations do not follow the expected relationships over the entire range of single fiber breaking elongation. The fabric breaking elongations in all fabric conditions for

the Hybrid cotton are higher than would be expected on the basis of the single fiber breaking elongation. On the other hand, the fabric breaking elongations for the Lengupa cotton are considerably lower than would be expected on the basis of its single fiber breaking elongation.

In the same manner that it was possible to calculate breaking tenacity transmission coefficients, it is possible to calculate breaking elongation transmission coefficients. The breaking elongation transmission coefficient is defined as the ratio of the structure breaking elongation to the breaking elongation of the single fibers. These values are listed in Table VI.

It is of interest to note the order of magnitude of the transmission coefficients, which can be done by examining the average values for the six cottons. The value of 0.86 for the Pressley bundles indicates a somewhat imperfect transmission of fiber extensibility from single fibers to Pressley bundles. The improved transmission of fiber extensibility to yarns, indicated by a transmission coefficient of 1.00, is undoubtedly due to the twist in the yarns, which increases yarn breaking elongation. The value for the average transmission coefficient of 1.83 for fabrics indicates the added extensibility imposed by the fabric construction. Thus, in the case of breaking elongation, the geometry of the textile structure plays a particularly important role. Since these six cottons were manufactured under identical conditions into the same yarn counts and fabric constructions, it is, however, possible to compare them as far as breaking elongation is concerned.

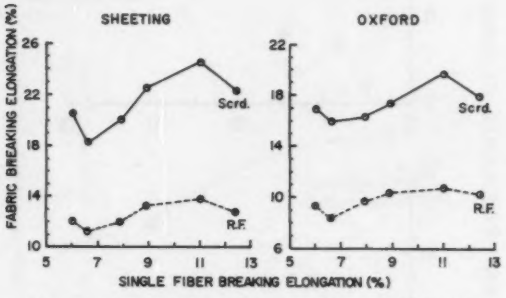

Fig. 8. Relationship between fabric and single fiber breaking elongation.

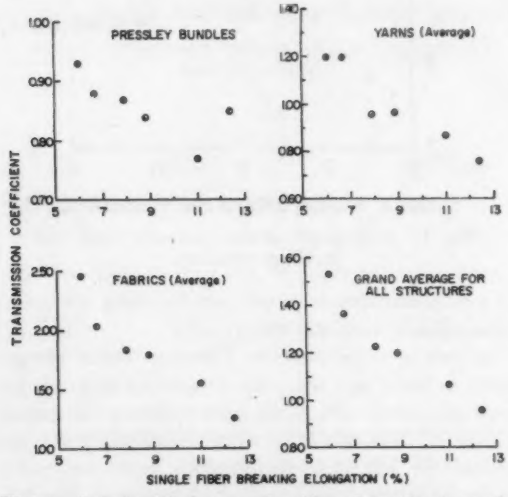

Fig. 9. Relationship between breaking elongation transmission coefficient and single fiber breaking elongation.

Considering the transmission coefficients for the three textile structures (bundles, yarns, and fabrics), examination of Figure 9 indicates that the breaking elongation transmission coefficient is an inverse function of the single fiber breaking elongation. Thus, cottons with a low fiber breaking elongation transmit this property to the resultant textile structures more efficiently than do cottons with a high fiber breaking elongation.

Discussion

In view of the fact that both in the case of breaking strength and elongation the transmission coefficients are an inverse function of the single fiber value, it is possible to deduce certain generalizations regarding the manufacturing operations and the influence of fiber properties on end product performance.

On the basis of the transmission coefficients it is apparent that the differences among the cottons in their single fiber state are reduced by the manufacturing steps so that corresponding end products such as yarns and fabrics do not show wide divergencies.

TABLE VI. Breaking Elongation Transmission Coefficients

Cotton	Pressley bundles, 5-mm. gauge	Yarns, aver.	Fabrics, aver.	Grand average
Pima S-1	0.77	0.87	1.57	1.07
Deltapine	0.88	1.20	2.04	1.37
Sea Island	0.84	0.97	1.80	1.20
Acala	0.87	0.96	1.84	1.23
Hybrid	0.93	1.20	2.46	1.53
Lengupa	0.85	0.77	1.27	0.96
Average	0.86	1.00	1.83	1.23

It is not suggested that the differences among cottons are completely eradicated, but rather that the basic differences among cottons in their single fiber state tend to be leveled out by textile processing operations.

This tendency at leveling-out differences among cottons may be shown in another manner. Consider the grand average breaking tenacity transmission coefficient for all three textile structures (bundles, yarns, and fabrics) as shown in the last column of Table V. If this grand average transmission coefficient for each cotton is multiplied by the single fiber breaking tenacity for each cotton, the product can be termed as the breaking tenacity of a hypothetical textile structure. This is shown in Table VII.

By means of a bar graph (Figure 10), a comparison is shown between the experimentally determined single fiber breaking tenacity and the hypothetical textile structure breaking tenacity. It is clear that the differences between the single fiber breaking tenacity and the hypothetical textile structure breaking tenacity are larger for strong cottons and that these differences become smaller as one considers the weaker cottons.

The same calculation can be made as far as breaking elongation is concerned from consideration of the grand average breaking elongation transmission coefficient and the single fiber breaking elongation. This is shown in Table VIII.

The bar graph in Figure 11 shows a comparison between the experimentally determined single fiber breaking elongation and the hypothetical textile structure breaking elongation. Similar to the strength characteristic, the differences between the single fiber breaking elongation and the hypothetical textile structure breaking elongation are larger for low elongation cottons than for high elongation cottons.

On the basis of the results presented in this paper, one may draw the conclusion that textile processing operations tend to reduce differences among cottons. By no means should one conclude from this research that fiber properties are not transmitted to textile structures such as yarns and fabrics. On the con-

TABLE VII. Breaking Tenacity of Hypothetical Structure

Cotton	Single fiber breaking tenacity, g./grex	Grand average transmission coefficient	Hypothetical textile str. brk. tenacity, g./grex
Pima S-1	4.25	0.50	2.12
Deltapine	2.30	0.60	1.38
Sea Island	3.31	0.56	1.85
Acala	2.76	0.59	1.63
Hybrid	3.90	0.52	2.03
Lengupa	3.31	0.42	1.39

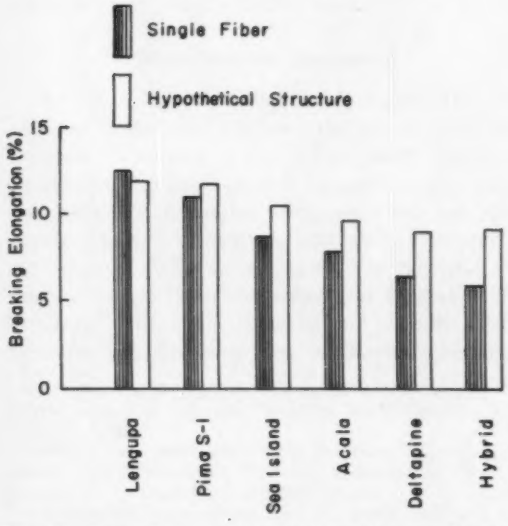

Fig. 10. Comparison of single fiber breaking tenacity with hypothetical textile structure breaking tenacity.

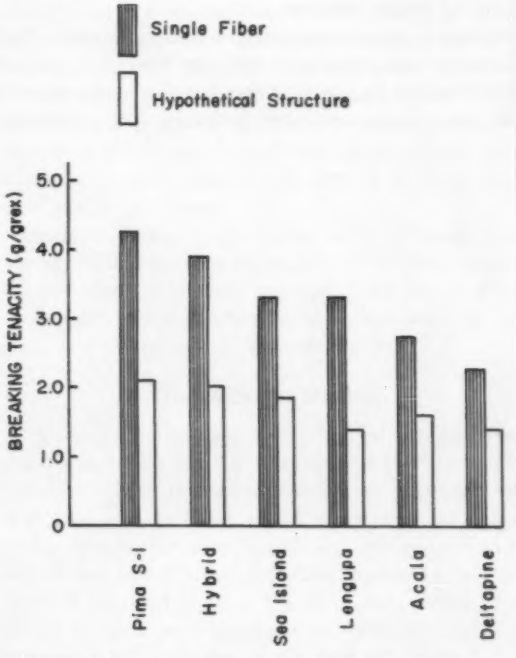

Fig. 11. Comparison of single fiber breaking elongation with hypothetical textile structure breaking elongation.

TABLE VIII. Breaking Elongation of Hypothetical Structure

Cotton	Single fiber brk. elong., %	Grand aver. trans. coef.	Hypothetical structure brk. elong., %
Pima S-1	11.0	1.07	11.8
Deltapine	6.6	1.37	9.0
Sea Island	8.8	1.20	10.6
Acala	7.9	1.23	9.7
Hybrid	6.0	1.53	9.2
Lengupa	12.4	0.96	11.9

trary, the differences among the experimental cottons in fiber strength and extensibility are clearly evident in the textile structure properties, as is shown in the relationships in Figures 1–4 and 6–8. The point that is made here is that the differences are not as large in the textile structure as they are in the single fiber state. The basic differences among cottons as far as breaking strength and elongation are concerned tend to be leveled out and reduced by a combination of factors. These factors include not only the interplay of other fiber properties which are either directly or indirectly associated with strength and extensibility, but also the leveling-out tendencies of textile manufacturing operations and the geometrical configurations of textile structures.

Since in many cases extreme values of a given fiber property are introduced into the fiber, not only at considerable financial expense but also at the expense of some associated fiber property (e.g., stiffness, fineness, length), it is important that the processing conditions and operations be so adjusted that the extremeness of the fiber property under question be maintained.

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An Investigation of Air Pressures in the Cotton Carding Machine[1]

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Abstract

An investigation is reported of the air pressures in the conventional cotton card, measured at strategic points with the card running idle and when processing cotton. Through the utilization of a sensitive electronic instrument capable of measuring pressures of 0.001 in. of water, both static and velocity determinations were made that have given an insight into the function of air in the card and have led to the development of a method of carding without the use of the conventional revolving flats.

Introduction

For many years there have been discussions of the function of air in the operation of the standard cotton carding machine [3, 6]. Three years ago the authors undertook an investigation of carding aerodynamics; the results indicated that air contributes a relatively minor part in the actual mechanics of fiber separation and is, in general, more detrimental than helpful. The studies have led to the development of a method of carding without the use of revolving flats. This paper presents a brief summary of the air measurements; a separate paper [5] discusses results obtained with the SRRL flatless card.

Experimental Procedure

One of the major difficulties of investigating air currents in the card has been the minute pressures involved. Previous workers have been hampered by the fact that draft gauges, vacuum gauges, water manometers, and similar instruments are not sufficiently sensitive to measure accurately pressures in the range of 0.001 in. of water. In the past few years electronic instrumentation has overcome this handicap. The static pressure and velocity determinations reported here were made with a Hastings Electronic Manometer,[3] which is capable of 0.001 in. direct reading, and can be estimated to 0.0005 in readings lower than 0.005 in.

The studies were conducted on a 1948 model standard revolving flat card, carefully ground and adjusted in accordance with the manufacturer's recommendations. The card room at the Southern Laboratory is operated under controlled atmospheric conditions; air measurements were made at times when conditions were practically constant at 58% relative humidity and 75° F. temperature.

The experimental setup is shown in Figure 1, and the points of measurement are schematically depicted in Figure 2. Measurements were made at three locations across the width of the card 6 in. from each side and at the center.

Static and velocity pressures were determined between the flats and the main cylinder at three points; at the clearance between the tips of the wires of the flats and cylinder, at the knee of the wire on the flats, and at the base of wire on the flats.

Discussion of Results

An investigation was first made of the static air pressures which exist at the back of the card. The pressure under the lickerin cover at the point "9" was found to be 0.046 in. of water with no cotton being processed and 0.140 in. of water when cotton was being processed. The pressure below the nose of the feed plate in the mote box remained at 0.005 in., with or without cotton. This difference in pressure above and below the nose of the feed plate revealed that considerable air was blowing through

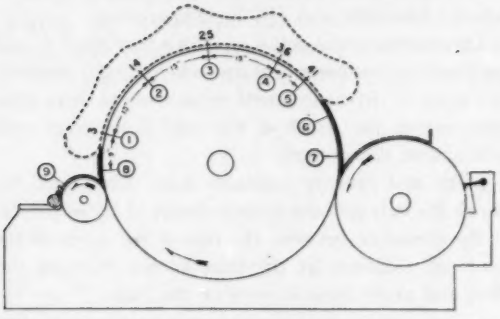
[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, North Carolina, February 14, 1958.

[2] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

[3] Mention of trade names does not imply their endorsement by the Department of Agriculture over similar products not mentioned.

the fringe of the lap and following the lickerin down to the mote knives. Eliminating the air entrained by the lickerin was accomplished by replacing the lickerin cover with a box type enclosure, somewhat similar to one mentioned by other investigators [1], incorporating a means to relieve air pressure and at the same time filter out the fiber and return it to the feed. Patent protection is pending on this new cover. Figure 3 shows the air pressures that exist around the lickerin with the standard and with the modified cover. Results obtained with the cover are shown in Table I.

Fig. 1. Photograph of electronic manometer and card.



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Measurements of static air pressures between the cylinder and flat bars were made by means of a ¼-in. diameter tube inserted through a flat bar. A graphic picture of these measurements with and without cotton being processed through the card is shown in Figure 4. Flat 1 is the bar just above the back knife plate. The high pressure at this point is believed due to the air from under the knife plate being discharged toward and under the oncoming flat. The curves show a decrease in pressure for the first six flat bars, indicating that the air continues to escape for that distance. The discharge of air accounts in part for the rapid loading of flats in the first few positions that has been reported by other researchers [2].

Figure 5 shows graphically the static air pressures at the tips and base of the flat wires. Because of the very minute pressures that were measured, and the possible influence of eddy currents and card adjustments, these data should be viewed as a very general picture of a flexible set of conditions. These data have been summarized on an outline of the card which schematically shows the air pressures around the cylinder.

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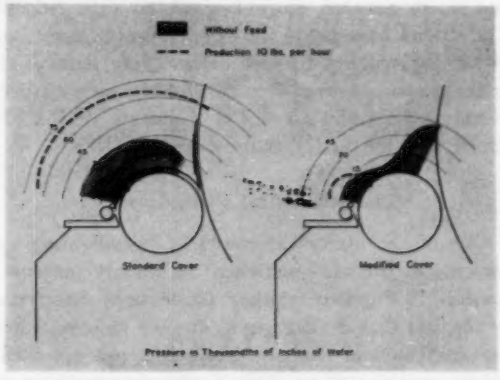

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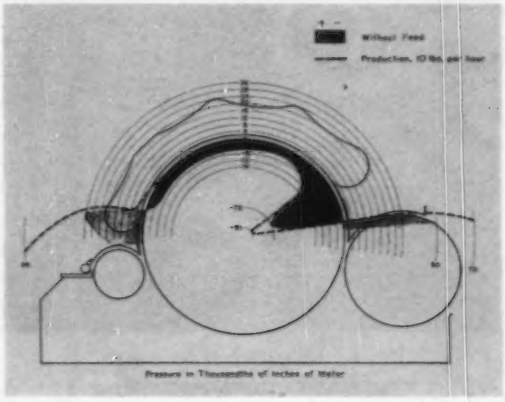


Fig. 6. Static air pressures around the card main cylinder.

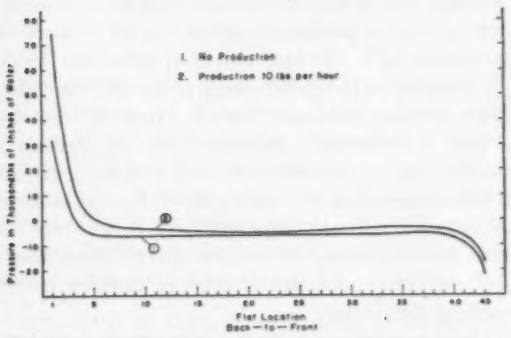
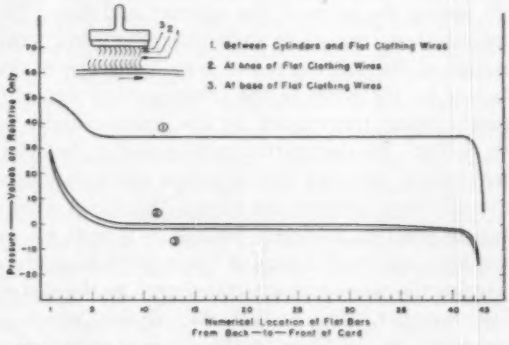


Fig. 4. Static air pressures between the cylinder and flats.


1. Between Cylinders and Flat Clothing Wires
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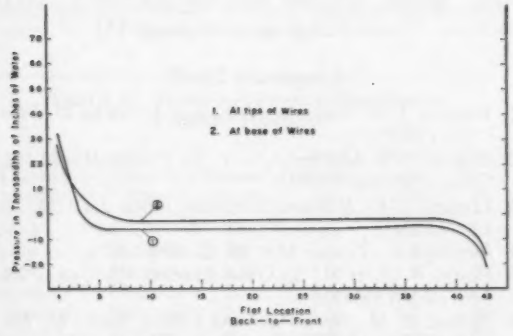
Pressure ——Values are Relative Only
Numerical Location of Flat Bars
From Back—to—Front of Card

Fig. 7. Velocity plus static pressure in wires of flats with no production.



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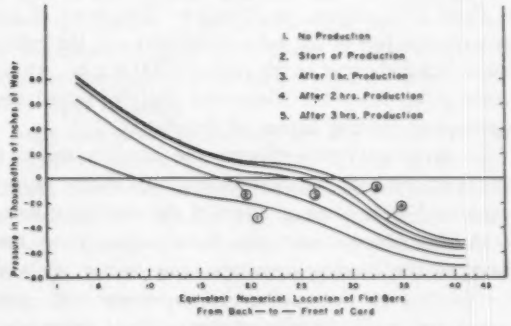
1. No Production
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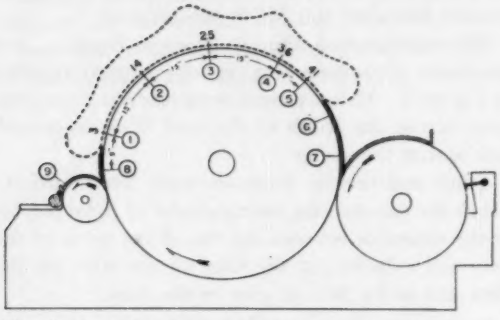

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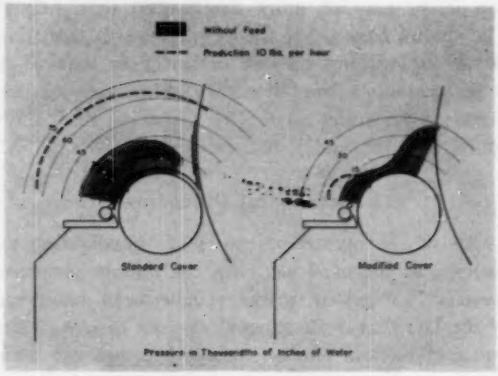

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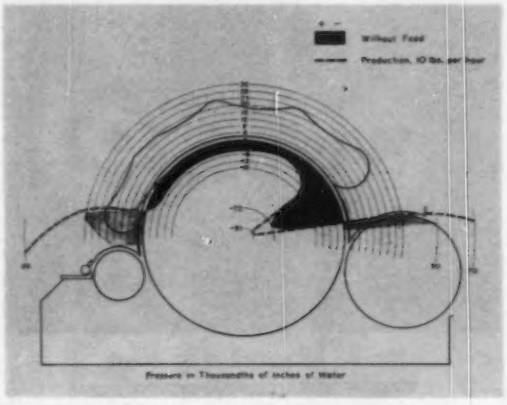

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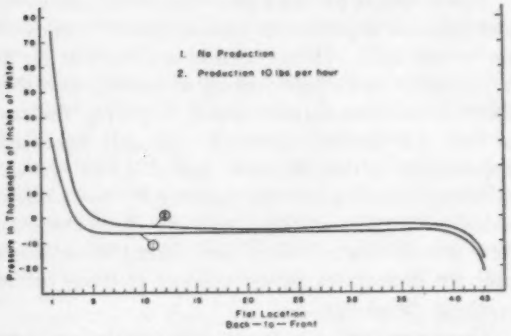

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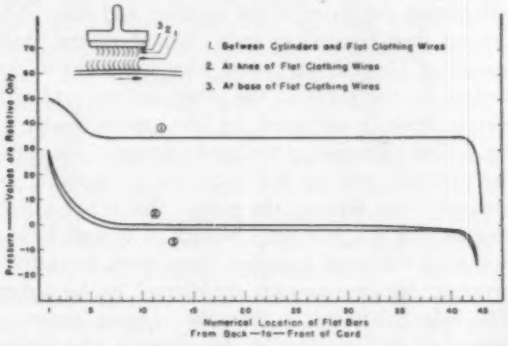
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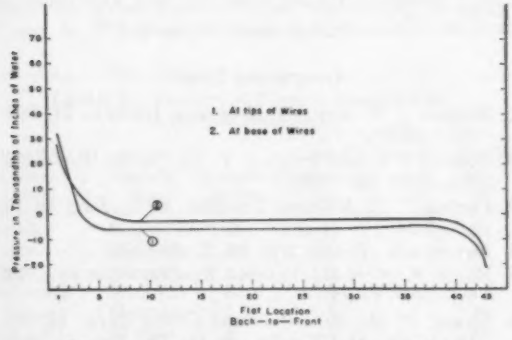

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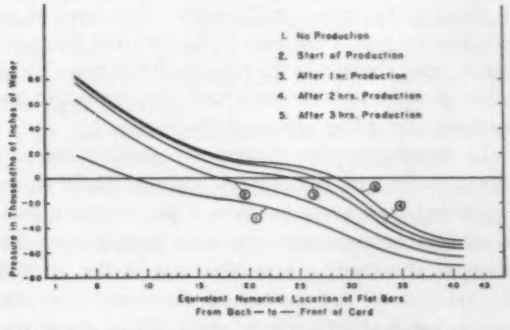
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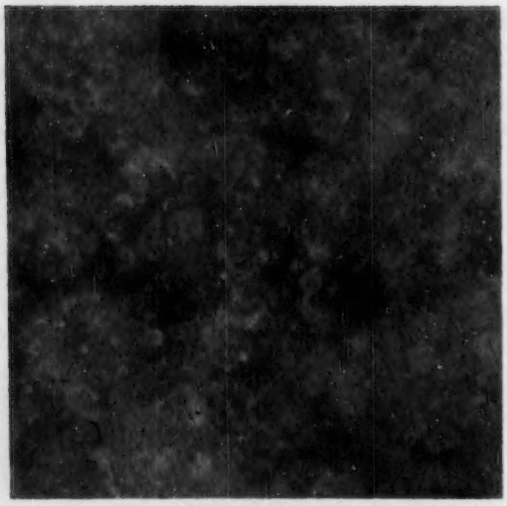

Fig. 9. Photograph of cotton web.

the cylinder are carried into the flats and, within the distance of the first few flats, are opened and spread out among the wires of the cylinder and flats. The process then consists of individual fibers and small groups of fibers being pulled from the wires of one surface by the wires of the other surface, and ultimately being transported by the main cylinder to the doffer. Because of the positive rake of the cylinder clothing, only the individualized fibers should be removed from between the wires. This is not wholly true in practice, however, because it is well known that neps and small lumps of fibers work loose from between the wires and are transferred to the doffer. The essential point is that the carding action is dependent on the fibers in the wires of one surface being contacted by the wires of the other surface. The difference in speed between these two surfaces is about 2200 ft.p.m., or 25 m.p.h. The layer of air between the tips of the wire of the flats and the cylinder is being sheared at the rate of 2200 ft.p.m., which tends to lay back the fibers and thereby retard the mechanical carding action of the flats.

To investigate this theory, the carding machine was operated with the cylinder enclosed by the aforementioned steel cover in place of the revolving flats. With this arrangement, the force acting upon the fibers in the carding area was that of the air and the friction of the surface of the cover. It was assumed that the friction of the polished cover was minor compared with the friction of the air. Cottons were processed with clearances between the cover and the cylinder of 0.005, 0.010, 0.027, 0.068, 0.125, 0.250, and 0.375 in. Since the low quality of the web would not permit nep counts, evaluations were made by visual comparisons of the appearance of nep boards. No differences were detected in the web for the different settings of the cover. This experiment indicated that the air was relatively ineffective in the carding area of the machine, and that the fibers must be subjected to mechanical action to accomplish any degree of fiber separation. The recent findings of the Hungarian investigator Merenyi [4] support the theory that carding is a mechanical action. Based on experiments and calculations, this investigator reported the average mechanical carding force to be about 40 times greater than the shearing force of air currents, while the pulling force necessary to separate a fiber from cotton clumps was about 4000 times the shearing force of the air currents.

Conclusion

A brief report has been given on air measurements and physical experiments carried out in a study of the cotton card. It has been concluded that air is not a major factor contributing to carding, and that there is no fundamental reason requiring the use of flats for carding. Basically the only necessary requirement is that the tufts and unopened groups of fibers deposited on the cylinder by the lickerin encounter a resistant force sufficient to separate the tufts into individual fibers and spread these fibers over the entire area of the cylinder clothing before reaching the doffer.

These conclusions were put into practical application in the development of the SRRL card without flats. Results achieved with the new experimental card are discussed in a separate paper [5].

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4. Merenyi, G., *Textile Mfr.* **83**, 27–30 (1957).
5. Rusca, R. A. et al., TEXTILE RESEARCH JOURNAL **28**, 597–599 (1958).
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Carding Without Flats—A Report on the SRRL Card[1]

R. A. Rusca, A. L. Miller, and R. S. Brown

Southern Regional Research Laboratory,[2] New Orleans, Louisiana

Introduction

A method for carding without flats has been developed at the Southern Regional Research Laboratory. The results achieved with the experimental card will be discussed in this paper; however, it is regretted that only limited disclosure of design details can be made pending the filing of patents. It is expected that full engineering information will be available within the year.

Carding Apparatus

The SRRL development is a simple, fixed mechanism that replaces the flat assembly and flexible bends on conventional flat top cotton cards. It also may be applicable to roller top cards. The apparatus weighs less than 200 lb., as compared to about 1000 lb. for the assembly it replaces. It completely seals the top of the card, thereby eliminating a major source of dust and fly. The apparatus in itself has no moving parts; however, associated with it are minor changes made in the lickerin setup. After removal of the flats, installation can be made in 3–4 hr. by two men. Initial cost should not be excessive; the original unit for experimentation cost $1100, but this should be halved easily with any reasonable production. Maintenance should be very low, since only one part of the apparatus is subject to wear; so far there is no evidence of wear after intermittent operation for 1 yr. There is no cost of operation because there is no waste to strip and the device requires no power. Total card power consumption is reduced about one-eighth horsepower.

Experimental Procedure

Briefly, the evaluation procedure consisted of comparing the results from a standard card with those from a card without flats, both operating under carefully controlled experimental and atmospheric conditions. The standard and experimental cards were identical 1948 models with relatively new cylinder and doffer clothing, ground and set to the manufacturer's recommendations. Results from the same card with flats and without flats were also compared.

Six cottons were used in the tests (Table I), ranging from $\frac{31}{32}$-in. Texas to $1\frac{7}{16}$-in. American Egyptian type from New Mexico. The cottons were processed identically through a conventional opening-picking line, except that one of the cleaning points was omitted for the Pima S-1.

A summary of the results are presented in a series of figures and tables. All data are the average of three replications. The experimental card produced no flat waste (Figure 1). There is little difference between the experimental and standard cards in the other types of waste.

Neps and sliver uniformity are the major criteria of carding quality (Figure 2). There is no significant difference in neps between the experimental and standard cards at the same production rate, while at increased production the experimental card produces more neps. Sliver uniformity is slightly better with the experimental card.

Analysis of the fiber length distributions of the cylinder and doffer strips and the sliver by means of

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 14, 1958.

[2] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

TABLE I. Variety and Physical Properties of Cottons Processed

Cotton variety	Growth area	Classer's grade	Classer's staple, in.	Micronaire unit	Maturity,* %
Rowden	Waco	M	$\frac{31}{32}$	4.3	84
Coker	Memphis	M	$1\frac{1}{16}$	4.4	87
Coker	Memphis	LM	$1\frac{1}{16}$	4.2	87
Deltapine	Memphis	LM	$1\frac{1}{16}$	4.6	89
Unknown	Memphis	LM	$1\frac{1}{16}$	4.7	84
Pima S-1	El Paso	2	$1\frac{7}{16}$	3.5	86

* Sodium hydroxide method.

Suter-Webb fiber arrays shows no difference between cards, and no evidence of fiber damage. There is a very slight decrease in yarn strength and equal or slightly less strength uniformity for the experimental card at the same production rate (Figure 3). For a 50% increase in production, the data indicate decreased quality.

The extra-long staple Pima S-1 was also manufactured into combed yarns. A comber setting that produced 11.2% noils for cotton processed through the standard card produced about 0.5% more noils with cotton from the experimental card (Table II). A 1.5% increase in noils is noted for the comber setting that produced 13.0% noils for the standard card. Fiber length distribution studies of the noils and sliver reveal no difference between the two types of cards and no damage to this $1\frac{7}{16}$-in. length cotton.

At the low noil percentage and standard production rates, the experimental card gave slightly lower single strand strength and the same skein strength. With higher noils removal, single yarn strength was essentially the same and skein strength less. In general, no definite trend appears for either strength or yarn uniformity.

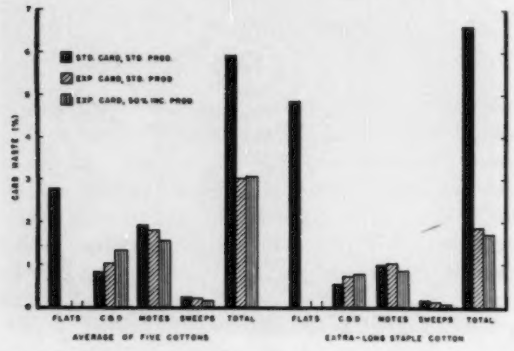

Fig. 1. Waste removed by experimental and standard cards.

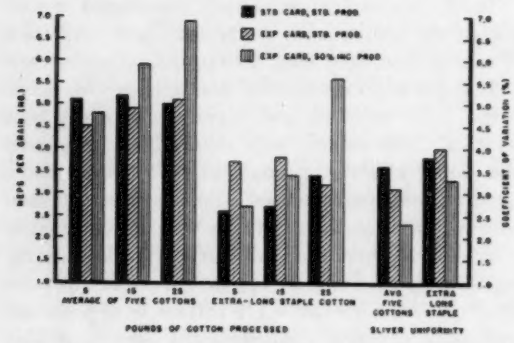

Fig. 2. Neps and sliver uniformity of experimental and standard cards.

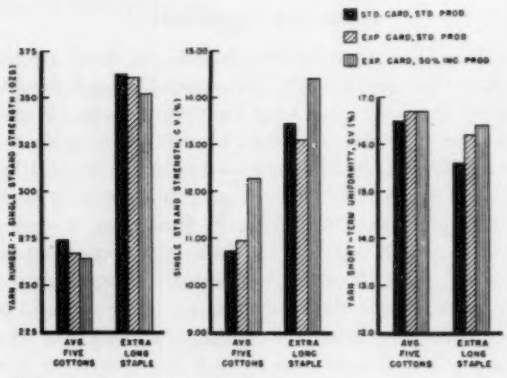
STD. CARD, STD. PROD.
EXP. CARD, STD. PROD.
EXP. CARD, 50% INC. PROD.
YARN NUMBER-B SINGLE STRAND STRENGTH (LBS.)
SINGLE STRAND STRENGTH, C.V. (%)
YARN SHORT-TERM UNIFORMITY, C.V. (%)
AVG. FIVE COTTONS
EXTRA LONG STAPLE

Fig. 3. Quality of carded yarns from experimental and standard cards.

TABLE II. Quality of Combed 60/1 Yarn from Cotton Processed Through Experimental and Standard Cards *

Card	Prod. rate, lb./hr.	Noils, %	Single strand CSP, no.×oz.	Single strand CV, %	Single strand Elong., %	Skein CSP, no.×lb.	Skein CV, %	Yarn unif. 4 ypm CV, %	Yarn unif. 25 ypm CV, %
			Low noil percentage						
Standard	4	11.2	380	11.69	6.4	2822	8.40	13.8	14.0
Experimental	4	11.7	375	13.14	6.5	2825	6.71	13.8	14.3
Experimental	6	12.0	376	12.47	6.4	2867	8.30	14.1	14.6
			High noil percentage						
Standard	4	13.0	390	12.09	6.4	2890	7.27	13.6	13.6
Experimental	4	14.5	389	12.25	6.7	2807	6.70	13.8	14.6
Experimental	6	14.6	378	12.10	6.4	2840	7.56	13.9	14.2

* Pima S-1, $1\frac{7}{16}$-in. cotton.

TABLE III. Effect on Waste and Quality of Converting a Revolving Flat Card to Carding Without Flats

Card	Prod. rate, lb./hr.	Waste: Strips: flats, %	Waste: Strips: C&D, %	Waste: Motes & fly, %	Waste: Sweeps, %	Waste: Total, %	Trash content: Lap, %	Trash content: Sliver, %	Sliver unif. CV, %
With flats	10	3.06	0.85	1.53	0.37	5.81	2.11	0.33	3.09
Without flats	10	0.00	0.70	1.74	0.19	2.63	2.18	0.33	2.58

Card	Prod. rate, lb./hr.	Neps/grain after: 5 lb.	Neps/grain after: 15 lb.	Neps/grain after: 25 lb.	Single strand strength: CSP, no.×oz.	Single strand strength: CV, %	Yarn unif. CV, %	Skein strength: CSP, no.×lb.	Skein strength: CV, %
With flats	10	6.0	6.6	5.6	273	11.4	16.7	2157	4.1
Without flats	10	3.6	3.1	3.9	268	12.8	16.8	2100	4.0

* Standard 1948 model card data are average of three replications.

These evaluations of the extra-long staple cotton cannot be considered conclusive in view of the fact that they were conducted with a single bale of Pima cotton.

Identical cottons were then processed through the same card, first equipped with conventional flats and then with the carding apparatus substituted for the flats. Results, presented in Table III, are favorable to carding without flats.

Summary

In summary, an apparatus has been developed for converting conventional cards to carding without revolving flats. The device is simple, relatively inexpensive, and effective. It eliminates all flat waste, reduces dust and fly, decreases maintenance, and materially decreases the weight of the card.

Evaluations of the apparatus under pilot plant conditions show reductions of 50–75% in overall card waste, about the same nep count, and slightly more uniform sliver when compared with a conventional card in excellent condition. On the same card equipped with flats and without flats, waste is reduced 50%, neps about 30%, yarn strength is 2% less, and yarn uniformity is the same. The apparatus appears to perform equally well on short, medium, and extra-long staple American cottons.

It is anticipated that design details of the SRRL Carding Apparatus will be publicly available within the year.

Acknowledgment

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A Study of the Effect of Half Lap Needling on Combing Efficiency[1]

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Abstract

The functions of the comber half lap needle segment and the effect of its design on waste removal are described. Results of some mill trials using different needling specifications are given.

IN reviewing the literature, it was surprising to note how little work has been published on the subject of combing in comparison with other phases of textile research, such as opening, cleaning, picking, carding, drawing, and spinning. It appears from this literature search that up until approximately ten years ago, relatively little interest had been shown in combing research, but immediately after the war, when emphasis was placed on increased productivity and reductions in waste, floor space requirements, and labor costs, it was natural that the combing process be re-evaluated in light of these factors.

One of the best known works that has been published in the past few years is the work of Morton and Neild of the University of Manchester in England. Morton and Neild investigated the effect of precomber preparation on waste extraction at the comber and found that the number of processes used between the card and the comber has a major effect on the amount of waste extracted at the comber. They concluded that there should be an even number of processes between carding and combing for maximum efficiency as regards waste removal. The theory on which their conclusions are based is that the fibers coming out of the card show a preponderance of trailing hooks, and with an even number of processes between carding and combing, these trailing hooks produced at the card are fed into the comber as leading hooks. At the comber, these hooked fibers are straightened out and act as unhooked fibers, i.e., their true length. If the hooked fibers produced at the card are fed into the comber as trailing hooks, however, the effective length of these fibers is considerably shorter than their true length. Since the comber is basically a length fractioning machine, trailing hooked fibers are treated as short fibers, and in most cases are removed as noils. Thus a considerable number of long fibers may be unnecessarily extracted at the comber as noils. This condition certainly pleases the waste merchant, but its effect on mill operation is that the mill has to set its combers to take out more waste than necessary to get the same sliver quality as is obtained when an even number of processes are used between carding and combing.

During the past ten years considerable advances have been made by the machinery manufacturers in regard to combing equipment. Combers are now available which can produce equal or better work at 128–150 nips/min. with production rates up to 60 lb./hr. and at lower waste extractions than was possible approximately 10–15 yr. ago, when the average comber was being operated at approximately 90–100 nips/min. at a production rate of about 15–20 lb./hr. Considering the improvements that have been made in the past 10–15 yr. on the factors mentioned previously, i.e., production rate, labor costs, waste, and floor space requirements, we must agree that large advances have been made in the field of combing research.

Because we produce sewing threads, in which most of the yarn used is combed and made from long staple cottons, the combing process has always been of great interest to Coats & Clark. The improvement in combing efficiency has been a goal of our manufacturing and research personnel since the first combers were installed in our plants many years ago.

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 12, 1958.

Approximately three years ago, an extensive combing research project was set up with a goal in mind of restudying the basic actions of the comber to determine the function of each part and how each part functions in relation to the others. The purpose of this study was twofold: (1) to study the actions of our present combers to determine the effect of changes in settings and timings on combing efficiency, and, having done this, (2) to determine the optimum combination of settings and timings to give maximum combing efficiency (Let us limit, for the purpose of this discussion, the definition of maximum combing efficiency as the condition resulting from a minimum of long fiber in the noils and short fiber in the sliver with a minimum of fiber breakage.); and with the present combers operating at maximum efficiency, to compare them with the new combers presently available on the market.

The greatest portion of time that has been and is still being spent in this investigation is on a study of the half lap needle segment. It was felt to be quite logical to concentrate our investigations there, inasmuch as all other parts of the comber have been devised and timed to bring cotton properly prepared to it and away from it. Therefore, the importance of comber needling in the proper functioning of the comber cannot be overlooked. Inasmuch as the best needling specification for a half lap would be ineffective with an improperly set and timed comber, a series of settings and timings were theoretically determined through the use of a timing diagram; the practicality of these theoretical settings and timings was determined through experimentation within the limitations of the available combers. After this had been done, our full attention was devoted to the determination of the needling specifications which would give us maximum combing efficiency.

The function of the half lap needle segment is twofold; it should remove all fibers shorter than a predetermined length and also remove particles of trash and nep. The degree of short fiber, trash, and nep removal is, of course, based on the desired quality of the end product.

The theory of half lap needling is based on progressive increases in the severity of the combing action from the time the needles of the first needle bar enter the beard to be combed until the last row of needles leaves the beard. Therefore, the size, spacing, and length or projection of needles has a significant effect on the quality of the combed product. To obtain this progressive combing action, the needles are coarse, widely spaced, and relatively long in the first rows, and become finer, closer, and shorter in projection in succeeding rows. The angle at which the needles are inclined is fairly steep so that the first rows of needles will definitely catch in the beard projecting from the nippers and lead the fibers down to the base of the needles. Therefore, the first rows do relatively little combing, inasmuch as their function is to catch the beard, do some straightening of fibers, and possibly remove large particles of trash. After the first rows of needles have started the combing, succeeding needle bars with finer, more closely spaced needles do a more complete combing job. Since the needles of these bars are finer, their length is reduced so that they will have the necessary stiffness to do their work. The spacing of the needles on the first few rows, therefore, is quite critical inasmuch as if the needles are too closely spaced together, three things may occur:

1. If the needles penetrate the beard, the closely spaced needles may pluck bunches of fibers out of the nipper with a resultant loss of long fiber.
2. If the closely spaced needles penetrate the beard, unnecessary fiber breakage may occur due to the high impact forces exerted on the cotton fibers.
3. The beard projecting from the nipper, rather than being pulled down to the base of the needles, will bounce along the top of the first few rows and be pulled down into the needles at about the sixth or seventh row. Therefore, instead of having seventeen rows of needles combing the beard, with a gentle action in the first row to a very severe action in the last row, we start off with a moderately severe combing action going to a very severe action with only approximately eleven rows of effective combing.

An analogy to the second effect is that of combing of the hair on one's head. An ordinary pocket or household hair comb normally has two sides, a heavy toothed, widely spaced side and a fine toothed, closely spaced side. It is rather difficult to run the finely spaced portion of the comb through the uncombed hair without exerting excessive force and if one succeeds in doing so, broken hairs are normally found in the comb. One normally, therefore, runs the coarse portion of the comb through the hair to straighten it and then finishes the combing with the fine portion of the comb. Isn't it logical, therefore, that this procedure be followed in combing cotton?

Pictures taken by Saco-Lowell of the combing action using several half laps with different needle spacing arrangements indicate the bouncing effect to be rather common on most half laps, with some showing less of the bouncing effect than others. It must also be pointed out that with the present emphasis being placed on combing heavier laps, it makes sense to have more openly spaced needles in the first rows than was necessary previously with lighter laps, to overcome the bouncing effect.

In our efforts to determine the optimum needling specifications for Nasmith type combers, several comber manufacturers and reneedling companies were contacted for their suggestions as to the proper needling specifications for half laps and top combs which would be adaptable for combing cottons ranging in staple lengths from $1\frac{1}{16}$ in. through $1\frac{1}{2}$ in., which is the present range of staple lengths being combed by Coats & Clark. A comparison of this information to the specifications presently used in our mills and also those used in our mills 25 years ago showed all to be at variance with one another. Perusal of all this information indicated that the comber pin or needle sizes were shown in terms of a wire gauge system. Wherever decimal equivalents were also given, the wire gauge system used was sought. It was found, however, according to the information we had received, that several different wire gauge systems were being used by the comber manufacturers and reneedlers in specifying wire sizes. Inasmuch as the spacing between needles is determined from the number of needles per inch, the needle size, and the needle projection, one can well imagine the confusion that could exist if each reneedler used needles sized to different wire gauge systems to specify needle sizes. If this were true, and a half lap specification were given in terms of needles per inch, projection, and needle size in terms of a wire gauge system, two half laps made to this specification by two reneedlers who used different wire gauge systems for denoting needle sizes could be completely different as regards spacing between needles for each row. Due to the difference in needle spacing, the severity of the combing action of each half lap, even though each has the same specification, might be considerably different.

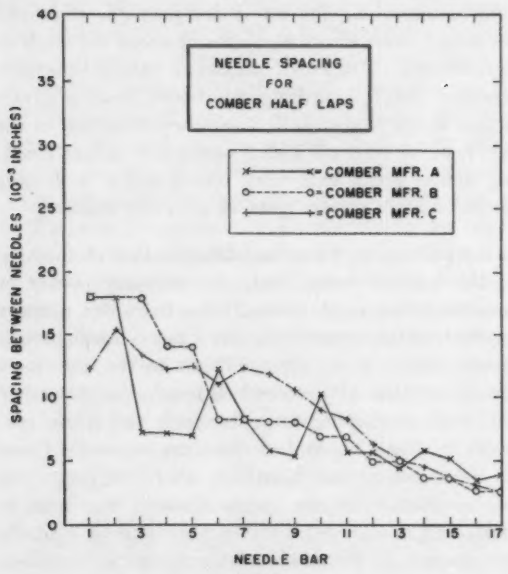

Fig. 1A.

We then wrote to the reneedlers that we had contacted previously and asked them for samples of the needles they used for reneedling half laps. Upon receipt of the needles from each source, they were measured and the decimal equivalent for each group of needles was compared to the needle size. According to our measurements, the needle size and corresponding decimal dimensions did not correspond to any known wire gauge system used in the United States. At this point, we learned that the majority of all comber needles were purchased from two sources; one in England, the other in Germany. It appeared that the English company had developed their own gauge system for needle sizes, and that this gauge system had been accepted, with minor variations, by all manufacturers of comber needles. This fact was brought to the attention of one of the comber manufacturers who specified that the needles used in their half laps be gauged according to one of the well known wire gauge systems used in this country. Some of their needle spacing calculations used in developing new half lap specifications were based on the use of needles sized according to this wire gauge system, whereas the actual size of the needles did not agree with the sizes specified. Fortunately, however, the differences between the actual and specified needle sizes had little effect on the efficiency of the half lap.

After the dimensions of the needles used in the half laps had been determined, all the needling information received from the comber manufacturers, reneedlers, and our own mills was analyzed on the

DATA FOR FIGURE 1-A

Half Lap Needling Specification—Comber Manufacturer A

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	22	22	3/16	0.0310	0.0285	0.0170
2	22	22	3/16	0.0310	0.0285	0.0170
3	28	22	3/16	0.0310	0.0285	0.0072
4	28	22	3/16	0.0310	0.0285	0.0072
5	30	22	5/32	0.0310	0.0263	0.0070
6	30	24	5/32	0.0245	0.0210	0.0123
7	34	24	5/32	0.0245	0.0210	0.0084
8	42	26	5/32	0.0195	0.0180	0.0058
9	52	28	5/32	0.0150	0.0138	0.0054
10	42	28	1/8	0.0150	0.0135	0.0103
11	52	28	1/8	0.0150	0.0135	0.0057
12	52	28	1/8	0.0150	0.0135	0.0057
13	63	30	1/8	0.0130	0.0115	0.0044
14	63	31	3/32	0.0120	0.0100	0.0059
15	66	31	3/32	0.0120	0.0100	0.0052
16	74	31	3/32	0.0120	0.0100	0.0035
17	80	33	3/32	0.0098	0.0086	0.0039

Half Lap Needling Specification—Comber Manufacturer B

1	22	22	3/16	0.0310	0.0285	0.0170
2	22	22	3/16	0.0310	0.0285	0.0170
3	22	22	3/16	0.0310	0.0285	0.0170
4	28	24	11/64	0.0245	0.0217	0.0140
5	28	24	11/64	0.0245	0.0217	0.0140
6	38	26	5/32	0.0195	0.0180	0.0083
7	38	26	5/32	0.0195	0.0180	0.0083
8	46	28	9/64	0.0150	0.0136	0.0081
9	46	28	9/64	0.0150	0.0136	0.0081
10	54	30	1/8	0.0130	0.0115	0.0070
11	54	30	1/8	0.0130	0.0115	0.0070
12	68	32	7/64	0.0110	0.0097	0.0050
13	68	32	7/64	0.0110	0.0097	0.0050
14	76	32	3/32	0.0110	0.0095	0.0037
15	76	32	3/32	0.0110	0.0095	0.0037
16	84	32	5/64	0.0110	0.0092	0.0027
17	84	32	5/64	0.0110	0.0092	0.0027

Half Lap Needling Specification—Comber Manufacturer C

1	26	22	0.156	0.0310	0.02625	0.0122
2	28	24	0.148	0.0245	0.02031	0.0154
3	30	24	0.140	0.0245	0.02000	0.0133
4	32	24	0.136	0.0245	0.01906	0.0122
5	34	26	0.132	0.0245	0.01688	0.0125
6	36	26	0.128	0.0245	0.01680	0.0110
7	38	28	0.124	0.0150	0.01400	0.0123
8	40	28	0.120	0.0150	0.01313	0.0119
9	44	29	0.116	0.0140	0.01200	0.0107
10	48	29	0.112	0.0140	0.01188	0.0090
11	52	30	0.108	0.0130	0.01094	0.0083
12	58	30	0.104	0.0130	0.01080	0.0064
13	64	31	0.100	0.0120	0.01040	0.0052
14	70	32	0.96	0.0110	0.00960	0.0047
15	76	32	0.90	0.0110	0.00936	0.0038
16	82	32	0.84	0.0110	0.00910	0.0031
17	88	32	0.78	0.0110	0.00880	0.0026

basis of the spacing between needles. As mentioned previously, it is this spacing that determines the severity of the combing action. To be in agreement with the theory, the spacing between needles should decrease progressively from the first needle bar to the last needle bar. The dimension of the needles and the projection of the needles above the needle bars determine the effective width of the needles at the solder line from which the spacing between needle calculations are made. Figures 1A, 1B, and 1C show a comparison of the needle spacing for several of the needle specifications we received from the comber manufacturers, reneedlers, and some of the old specifications used in our mills.

On the basis of this investigation, it is believed that the majority of mills and comber reneedlers have made little or no attempt to analyze comber needling in terms of the theory, but have thought that all that is necessary for a good needling specification is one that uses more and finer needles for each successive needle bar. When there are three variables interacting with one another all at one time, such as number of needles per inch, size of the needle, and projection of the needle, it is rather difficult, or almost impossible, to design a satisfactory half lap needling specification which would agree with the theory without calculating spacing between needles. This is the situation that exists today, in that over the past 20–25 years most mills and comber reneedlers have made changes in their half lap needling specifications based on processing difficulties and their own ideas as to how a half lap should be needled without considering the basic theoretical aspects of this problem. Furthermore, it is believed that reneedlers occasionally make substitutions in needle size when they run out of a given size, inasmuch as most of them believe that in the case of the finer needles, the dimensional difference between consecutive needle sizes is so slight that it should have little or no effect on the spacing between needles. However, considering the theory of comber needling, a substitution of a different size needle may result in a situation where the needle spacing, rather than decreasing in a successive row, increases after the substitution. This, in turn, eliminates one row of needles from having its maximum effect on the combing action. This may seem a little harsh on the reneedler; however, these points should be brought out in view of the fact that the great majority of mills today rely solely on the reneedler to furnish them with satisfactory half laps.

As regards the benefits to be derived from utilizing a half lap needling specification which is designed on the basis of the theory, each mill must decide for itself exactly what it wants. The following advantages can be obtained from the use of a theoretically

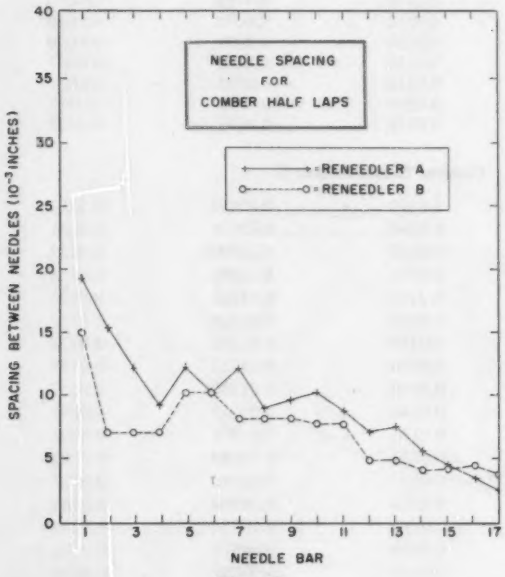

Fig. 1B.

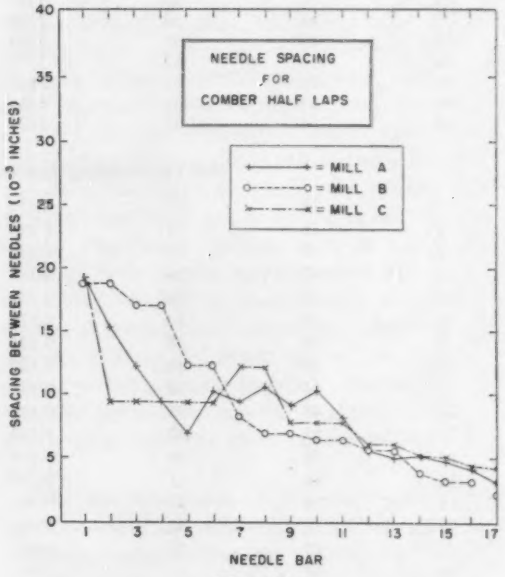

Fig. 1C.

good half lap needling specification *assuming the optimum settings and timings for the comber have been established*:

1. It should be possible, with the use of a properly needled half lap in which the needle spacing allows for a gentle combing action by the first rows and becomes increasingly severe from the first to the last row of the half lap, to eliminate plucking of bunches of fibers from the fiber beard which is to be combed. By eliminating this plucking action, a greater percentage of the long fiber available in the comber lap will go into the sliver and less long fiber will be extracted as noils.

2. The amount of waste removed for a given sliver quality can be reduced because of the greater amount of long fiber in the sliver.

3. Improved sliver quality can be obtained with the comber set to remove the same amount of waste as previously extracted because of the better fractionating characteristics of the half lap.

4. If a mill wants to improve its sliver quality and also reduce waste at the same time, a compromise value of waste extraction can be determined which will give the desired results. The results of tests conducted in our own mills have indicated that it is possible to do this.

To illustrate the advantages that can be obtained through the use of a theoretically good half lap specification, we would like to discuss some of the benefits that have been derived from a change in needling specifications on a group of Saco-Lowell combers we

DATA FOR FIGURE 1-B

Half Lap Needling Specification—Reneedler A

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	22	22	5/32	0.0310	0.0263	0.0192
2	24	22	5/32	0.0310	0.0263	0.0154
3	26	22	5/32	0.0310	0.0263	0.0122
4	28	22	5/32	0.0310	0.0263	0.0094
5	30	24	5/32	0.0245	0.0210	0.0123
6	32	24	5/32	0.0245	0.0210	0.0103
7	34	26	9/64	0.0195	0.0172	0.0122
8	38	26	9/64	0.0195	0.0172	0.0091
9	40	27	1/8	0.0175	0.0153	0.0097
10	42	28	1/8	0.0150	0.0135	0.0103
11	46	29	1/8	0.0140	0.0128	0.0089
12	50	29	7/64	0.0140	0.0128	0.0072
13	54	30	7/64	0.0130	0.0108	0.0077
14	62	30	3/32	0.0130	0.0103	0.0058
15	68	31	3/32	0.0120	0.0100	0.0047
16	73	31	3/32	0.0120	0.0100	0.0037
17	78	31	3/32	0.0120	0.0100	0.0028
			Half Lap Needling Specification—Reneedler B			
1	20	20	3/16	0.0390	0.0350	0.0150
2	28	22	3/16	0.0310	0.0285	0.0072
3	28	22	3/16	0.0310	0.0285	0.0072
4	28	22	3/16	0.0310	0.0285	0.0072
5	30	24	3/16	0.0245	0.0230	0.0103
6	30	24	3/16	0.0245	0.0230	0.0103
7	38	26	5/32	0.0195	0.0180	0.0083
8	38	26	5/32	0.0195	0.0180	0.0083
9	38	26	5/32	0.0195	0.0180	0.0083
10	46	28	5/32	0.0150	0.0138	0.0079
11	46	28	5/32	0.0150	0.0138	0.0079
12	56	29	7/64	0.0140	0.0128	0.0051
13	56	29	7/64	0.0140	0.0128	0.0051
14	66	30	7/64	0.0130	0.0108	0.0044
15	66	30	7/64	0.0130	0.0108	0.0044
16	68	31	5/64	0.0120	0.0100	0.0047
17	76	32	5/64	0.0110	0.0092	0.0040

DATA FOR FIGURE 1-C

Half Lap Needling Specification—Mill A

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	22	22	5/32	0.0310	0.0263	0.0192
2	24	22	5/32	0.0310	0.0263	0.0154
3	26	22	5/32	0.0310	0.0263	0.0122
4	28	22	5/32	0.0310	0.0263	0.0094
5	30	22	5/32	0.0310	0.0263	0.0070
6	32	24	5/32	0.0245	0.0210	0.0103
7	34	24	9/64	0.0245	0.0200	0.0094
8	36	26	9/64	0.0195	0.0172	0.0106
9	38	26	9/64	0.0195	0.0172	0.0091
10	42	28	1/8	0.0150	0.0135	0.0103
11	46	28	1/8	0.0150	0.0135	0.0082
12	54	29	7/64	0.0140	0.0128	0.0057
13	56	29	7/64	0.0140	0.0128	0.0051
14	64	30	3/32	0.0130	0.0103	0.0053
15	66	30	3/32	0.0130	0.0103	0.0049
16	70	31	3/32	0.0120	0.0100	0.0043
17	76	31	3/32	0.0120	0.0100	0.0032

Half Lap Needling Specification—Mill B

1	20	22	3/16	0.0310	0.0285	0.0187
2	20	22	3/16	0.0310	0.0285	0.0187
3	22	22	3/16	0.0310	0.0285	0.0170
4	22	22	3/16	0.0310	0.0285	0.0170
5	30	24	5/32	0.0245	0.0210	0.0123
6	30	24	5/32	0.0245	0.0210	0.0123
7	38	26	5/32	0.0195	0.0180	0.0083
8	40	26	5/32	0.0195	0.0180	0.0070
9	40	26	5/32	0.0195	0.0180	0.0070
10	50	28	1/8	0.0150	0.0135	0.0065
11	50	28	1/8	0.0150	0.0135	0.0065
12	55	29	1/8	0.0140	0.0125	0.0057
13	55	29	1/8	0.0140	0.0125	0.0057
14	65	30	1/8	0.0130	0.0115	0.0039
15	75	31	3/32	0.0120	0.0100	0.0033
16	75	31	3/32	0.0120	0.0100	0.0033
17	84	32	3/32	0.0110	0.0096	0.0023

Half Lap Needling Specification—Mill C

1	22	22	5/32	0.0310	0.0263	0.0192
2	28	22	5/32	0.0310	0.0263	0.0094
3	28	22	5/32	0.0310	0.0263	0.0094
4	28	22	5/32	0.0310	0.0263	0.0094
5	28	22	5/32	0.0310	0.0263	0.0094
6	28	22	5/32	0.0310	0.0263	0.0094
7	34	26	9/64	0.0195	0.0172	0.0122
8	34	26	9/64	0.0195	0.0172	0.0122
9	42	27	9/64	0.0175	0.0160	0.0078
10	42	27	9/64	0.0175	0.0160	0.0078
11	42	27	9/64	0.0175	0.0160	0.0078
12	53	28	3/32	0.0150	0.0128	0.0061
13	53	28	3/32	0.0150	0.0128	0.0061
14	66	31	3/32	0.0120	0.0100	0.0052
15	66	31	3/32	0.0120	0.0100	0.0052
16	81	33	1/16	0.0098	0.0079	0.0044
17	81	33	1/16	0.0098	0.0079	0.0044

have in our mills. The benefits discussed in this paper will be limited to those derived solely from changes in needling specifications. The benefits from increased productivity and reductions in labor cost and floor space requirements are secondary in nature, *only as regards the subject of this paper.* These latter benefits are, nevertheless, extremely important in considering the overall cost of the combing operation.

When this group of Saco-Lowell combers was originally installed in our mills, the machines were equipped with the Saco-Lowell Fossel half lap needling specification, Fossel being the designation given to the half lap specification by Saco-Lowell. Approximately three years later, when Coats & Clark initiated their study on the combing process, we evaluated the Fossel half lap on the basis of spacing between needles and found that it did not agree completely with the theory of decreased spacing between needles from the first to the last row (see Figure 2). At that time, we contacted Saco-Lowell and inquired as to the reasons for this disagreement. We were advised that a new half lap specification called the Pacific #5 had been designed which agreed much more closely with the theory of comber needling, and that tests made by Saco-Lowell had indicated that savings in waste and partial elimination of the bouncing effect of the fiber beard as it is contacted by the half lap were obtained. This specification was then analyzed in terms of spacing between needles, and although it produced a fairly smooth curve, indicating a progressive decrease in spacing between needles from the first to the seventeenth row of the half lap, there were still several rows in which the spacing increased from the preceeding row rather than decreased (see Figure 3). Assuming the theory to be correct, we submitted a modification of the Pacific #5 specification to Saco-Lowell for their comments. They, in turn, made some additional

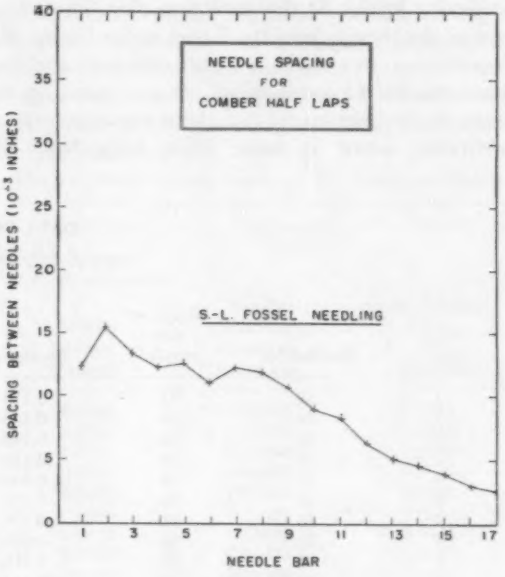

Fig. 2.

DATA FOR FIGURE 2

Saco-Lowell Fossel Half Lap Specification

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	26	22	0.156	0.0310	0.02625	0.0122
2	28	24	0.148	0.0245	0.02031	0.0154
3	30	24	0.140	0.0245	0.02000	0.0133
4	32	24	0.136	0.0245	0.01906	0.0122
5	34	26	0.132	0.0245	0.01688	0.0125
6	36	26	0.128	0.0245	0.01680	0.0110
7	38	28	0.124	0.0150	0.01400	0.0123
8	40	28	0.120	0.0150	0.01313	0.0119
9	44	29	0.116	0.0140	0.01200	0.0107
10	48	29	0.112	0.0140	0.01188	0.0090
11	52	30	0.108	0.0130	0.01094	0.0083
12	58	30	0.104	0.0130	0.01080	0.0064
13	64	31	0.100	0.0120	0.01040	0.0052
14	70	32	0.096	0.0110	0.00960	0.0047
15	76	32	0.090	0.0110	0.00936	0.0038
16	82	32	0.084	0.0110	0.00910	0.0031
17	88	32	0.078	0.0110	0.00880	0.0026

recommendations for modification; on the basis of these changes, what we call the Revised Pacific #5 specification was developed (see Figure 4). At this point, a comparison of the Fossel, Pacific #5, and Revised Pacific #5 specifications was made at the mill where our Saco-Lowell combers are installed. The results of this test indicated that when changing from the Fossel half lap to the Pacific #5 half lap, a saving in waste could be realized with no reduction in quality level. At the same time that the evaluation of the change from the Fossel to the Pacific #5 specification was made, we also evaluated the Revised Pacific #5 specification. It was found, on the basis of the tests made, that there was a consistent additional saving in waste when going from the Pacific #5 to the Revised Pacific #5. The later results surprised us somewhat in that only slight changes were made in four rows of the needle segment, and yet retest after retest showed this consistent additional saving in waste. The total saving in waste from these tests was approximately 2%. When one considers the savings in cotton involved in a reduction in waste of 2%, the financial gain to be made from a change in needling can be exceptionally large. On the basis of these tests, we have standardized the Revised Pacific #5 specification as the needling specification for all our Saco-Lowell combers.

Motion pictures taken by Saco-Lowell of the combing action with the Pacific #5 needling speci-

DATA FOR FIGURE 3

Saco-Lowell Pacific #5 Specification

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	18	22	0.156	0.0310	0.02625	0.0293
2	24	24	0.148	0.0245	0.02031	0.0214
3	25	24	0.140	0.0245	0.02000	0.0200
4	25	24	0.136	0.0245	0.01906	0.0209
5	32	26	0.132	0.0195	0.01688	0.0144
6	32	26	0.128	0.0195	0.01680	0.0145
7	36	27	0.124	0.0175	0.01440	0.0134
8	40	28	0.120	0.0150	0.01313	0.0119
9	44	29	0.116	0.0140	0.01200	0.0107
10	46	29	0.112	0.0140	0.01188	0.0099
11	52	30	0.108	0.0130	0.01094	0.0083
12	56	30	0.104	0.0130	0.01080	0.0071
13	64	31	0.100	0.0120	0.01040	0.0052
14	68	31	0.096	0.0120	0.01000	0.0047
15	76	32	0.090	0.0110	0.00936	0.0038
16	82	32	0.084	0.0110	0.00910	0.0031
17	88	32	0.078	0.0110	0.00880	0.0026
			Saco-Lowell Fossel Half Lap Specification			
1	26	22	0.156	0.0310	0.02625	0.0122
2	28	24	0.148	0.0245	0.02031	0.0154
3	30	24	0.140	0.0245	0.02000	0.0133
4	32	24	0.136	0.0245	0.01906	0.0122
5	34	26	0.132	0.0245	0.01688	0.0125
6	36	26	0.128	0.0245	0.01680	0.0110
7	38	28	0.124	0.0150	0.01400	0.0123
8	40	28	0.120	0.0150	0.01313	0.0119
9	44	29	0.116	0.0140	0.01200	0.0107
10	48	29	0.112	0.0140	0.01188	0.0090
11	52	30	0.108	0.0130	0.01094	0.0083
12	58	30	0.104	0.0130	0.01080	0.0064
13	64	31	0.100	0.0120	0.01040	0.0052
14	70	32	0.096	0.0110	0.00960	0.0047
15	76	32	0.090	0.0110	0.00936	0.0038
16	82	32	0.084	0.0110	0.00910	0.0031
17	88	32	0.078	0.0110	0.00880	0.0026

fication still indicate, however, a slight bouncing effect of the fiber beard when the beard is contacted by the first row of needles. It has been our feeling for quite some time that possible ways of eliminating the bouncing of the beard would be to curve the first row of needles so that the points of these needles enter the beard at right angles to the plane of the beard or increase the spacing between needles in the first few rows to allow for easier penetration of the needles.

The first solution tends to be impractical inasmuch as special needles would have to be produced; therefore the second solution was felt to be more advisable to pursue. Both of these suggestions were mentioned to Saco-Lowell. At the time they stated that they felt the increased spacing idea might have merit. During a very recent visit with them, they advised that they had developed a new needling specification called Eureka, utilizing flat needles, which practically eliminates the bouncing action of the beard when contacted by the first row of needles. They also felt that this new specification would allow for more efficient combing. An analysis of this specification on the basis of spacing between needles is shown in Figure 5. As can be seen, this new Eureka half lap specification agrees with the theory of half lap needling, but is considerably more open as regards spacing between needles in the first three rows than were previous Saco-Lowell specifications. This increased spacing should be especially advantageous when combing heavier laps.

The majority of our combers, however, are Heth-

DATA FOR FIGURE 4

Revised Saco-Lowell Pacific #5 Specification

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	18	22	0.156	0.0310	0.02625	0.0293
2	23	24	0.148	0.0245	0.02031	0.0232
3	25	24	0.140	0.0245	0.02000	0.0200
4	27	24	0.136	0.0245	0.01906	0.0180
5	30	26	0.132	0.0195	0.01688	0.0165
6	32	26	0.128	0.0195	0.01680	0.0145
7	36	27	0.124	0.0175	0.01440	0.0134
8	40	28	0.120	0.0150	0.01313	0.0119
9	44	29	0.116	0.0140	0.01200	0.0107
10	46	29	0.112	0.0140	0.01188	0.0099
11	52	30	0.108	0.0130	0.01094	0.0083
12	56	30	0.104	0.0130	0.01080	0.0071
13	61	31	0.100	0.0120	0.01040	0.0060
14	68	31	0.096	0.0120	0.01000	0.0047
15	76	32	0.090	0.0110	0.00936	0.0038
16	82	32	0.084	0.0110	0.00910	0.0031
17	88	32	0.078	0.0110	0.00880	0.0026
			Saco-Lowell Pacific #5 Specification			
1	18	22	0.156	0.0310	0.02625	0.0293
2	24	24	0.148	0.0245	0.02031	0.0214
3	25	24	0.140	0.0245	0.02000	0.0200
4	25	24	0.136	0.0245	0.01906	0.0209
5	32	26	0.132	0.0195	0.01688	0.0144
6	32	26	0.128	0.0195	0.01680	0.0145
7	36	27	0.124	0.0175	0.01440	0.0134
8	40	28	0.120	0.0150	0.01313	0.0119
9	44	29	0.116	0.0140	0.01200	0.0107
10	46	29	0.112	0.0140	0.01188	0.0099
11	52	30	0.108	0.0130	0.01094	0.0083
12	56	30	0.104	0.0130	0.01080	0.0071
13	64	31	0.100	0.0120	0.01040	0.0052
14	68	31	0.096	0.0120	0.01000	0.0047
15	76	32	0.090	0.0110	0.00936	0.0038
16	82	32	0.084	0.0110	0.00910	0.0031
17	88	32	0.078	0.0110	0.00880	0.0026

erington or Platt Nasmith Combers, all of which are 35–55 years old. The quality of work produced on these combers is still excellent and compares favorably with the quality obtainable with the new combers. It is impossible, however, to compare these Nasmith Combers to the new Saco-Lowell or Whitin combers on the basis of production rate, labor cost, and floor space requirements, simply because there is no comparison. The new combers are far superior to the old Nasmiths when compared on the basis of these three factors; however, on the basis of waste removed for a given quality of work, a question is raised as to whether the new combers can show considerable savings when compared to the old combers *when they are operating at maximum efficiency.* As mentioned previously, to obtain maximum efficiency on these old combers, it is believed that the half lap needling specification is of utmost importance. Several preliminary tests have been conducted over the past 1½ years in two of our mills having Nasmith combers on the effect of a change in half lap needling specifications; the results have indicated that there are potential savings in waste to be obtained with a change in needling specification with no effect on product quality, as was found with the Saco-Lowell combers. Of course, product quality is the final criterion upon which any change in needling specification is going to be made. If a mill is satisfied with its present quality level, all the savings can be taken in the form of waste reduction. If, however, an improvement in quality is desired, the savings can be taken in the form of a quality improvement with no change in waste removal. The

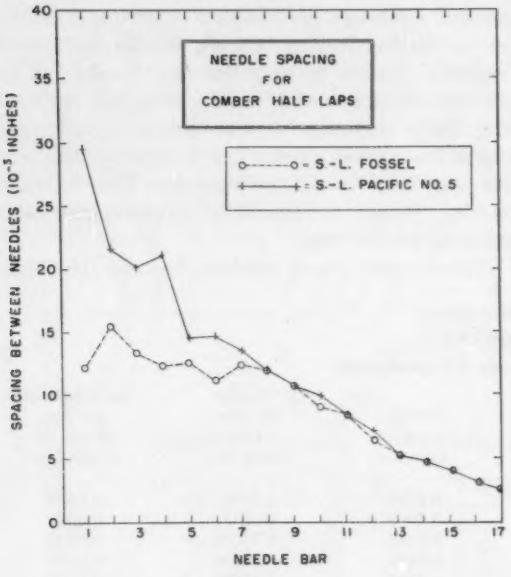

Fig. 3.

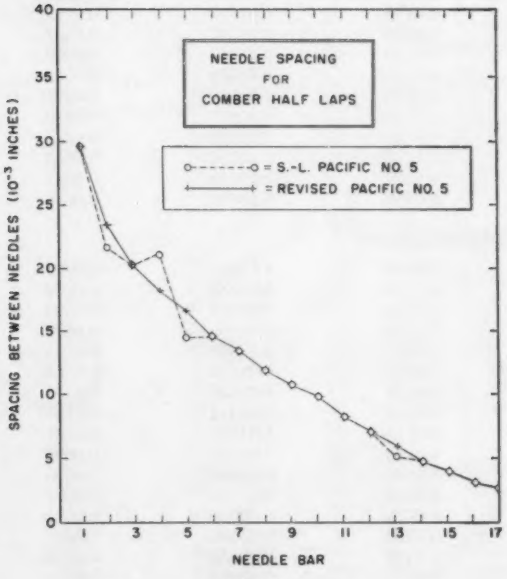

Fig. 4.

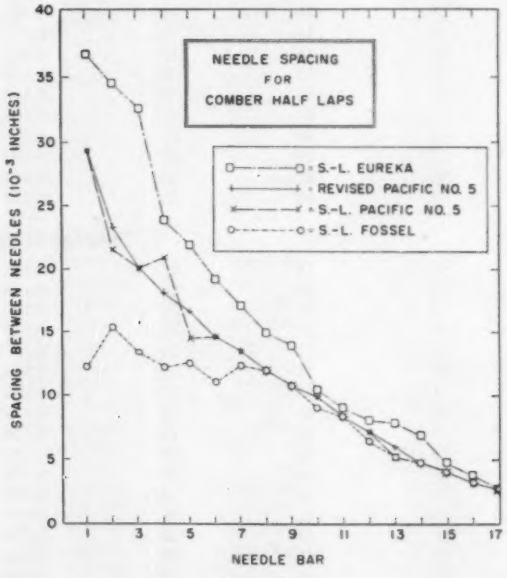

Fig. 5.

DATA FOR FIGURE 5

Specifications for Saco-Lowell Eureka—Flat Needle Half Lap

Strip no.	Needles/in.	Gauge or size needle	Projection	Needle gauge diameter	Needle diameter at root or solder line	Space between needles at root or solder line
1	20	20–26	0.186	0.0390–0.0195	0.01320	0.0368
2	21	20–26	0.178	0.0390–0.0195	0.01300	0.0346
3	22	20–26	0.170	0.0390–0.0195	0.01280	0.0327
4	28	22–28	0.162	0.0310–0.0150	0.01188	0.0238
5	30	22–28	0.154	0.0310–0.0150	0.01150	0.0218
6	33	22–28	0.146	0.0310–0.0150	0.01125	0.0191
7	36	23–29	0.138	0.0280–0.0140	0.01080	0.0170
8	39	23–29	0.132	0.0280–0.0140	0.01070	0.0149
9	41	23–29	0.126	0.0280–0.0140	0.01050	0.0139
10	53	24–30	0.120	0.0245–0.0130	0.00850	0.0104
11	58	24–30	0.114	0.0245–0.0130	0.00830	0.0089
12	62	24–30	0.108	0.0245–0.0130	0.00810	0.0080
13	55	31	0.102	0.0120	0.01040	0.0078
14	59	31	0.096	0.0120	0.01000	0.0069
15	71	32	0.090	0.0110	0.00936	0.0047
16	78	32	0.084	0.0110	0.00910	0.0037
17	88	32	0.078	0.0110	0.00880	0.0026

third alternative, of course, is a compromise, with part of the savings being taken in the form of waste reduction and the remainder in quality improvement.

We have just completed a large scale mill evaluation of a change in needling specification for Nasmith Combers involving several thousand pounds of combed stock. The results of this investigation have not been completely evaluated to date, but look quite promising. On the basis of this test, a final decision will be made by our Manufacturing Division as to the specification which will be adopted as a standard for all Nasmith combers in our mills.

When a mill determines that advantages can be obtained through a change in half lap needling specifications, it must then decide for itself on which basis it wishes to replace existing half laps. Inasmuch as half laps must be reneedled periodically, a mill has two alternatives as regards replacement of half laps when a new needling specification is adopted. These are (1) complete replacement in all combers at one time or (2) change to new specification on a replacement basis as the old half laps become unserviceable.

The factors determining the selection of an alternative normally will be based on (1) the savings and/or quality improvement that can be realized from a change in needling specifications and (2) capital availability.

If a mill changes to a new specification on the basis of replacement as the old half laps wear out, any savings realized will be made at no cost. It must be emphasized however, that the amount of the savings to be realized from a change in half lap needling specifications is largely dependent on the present level of waste extraction, the cost of the cotton being processed, and the efficiency of the present half laps. It is believed, however, that the savings involved are great enough, in most cases where old half lap specifications are being used, to pay for a complete installation of new half laps in every comber in a relatively short time.

Predicting Ends Down From Small Lot Spinning Tests[1]

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Abstract

The Poisson frequency function was used to translate the end breakage rate of 35 and 75/1000 spindles/hr. into a series of critical values which would be used to judge spinning performance in small lot spinning tests for various numbers of spindles used.

The critical values for various numbers of spindles used were determined graphically from the cumulative frequency of Poisson distribution.

A graph of these critical values for various numbers of spindles for the two levels of end-breakage has been constructed for a rapid evaluation of spinning performance.

Introduction

The problem of end breakage arises in all spinning practices; spinning lots with a normal end breakage rate will not only permit proper work loads, but will facilitate the subsequent manufacturing processes. With a proper end breakage rate, the production per man-hour will be increased and the quality of the end product will be improved.

When making certain mechanical changes in machine, or when evaluating a new crop cotton or a newly developed synthetic fiber, it is unnecessary to stress the importance of the determination of the end breakage rate as well as the evaluation of the yarn quality.

In many spinning mills, after precautions have been taken to eliminate all end breakages due to assignable causes, it is the general opinion that an end breakage rate of 35 ends down/1000 spindles/hr. is acceptable.

However, when conducting an end breakage test on a limited number of spindles, it is realized that without proper interpretation the results obtained cannot be directly related to actual mill conditions.

This paper is an attempt to translate the end breakage values for a limited number of spindles to those expected for a larger number.

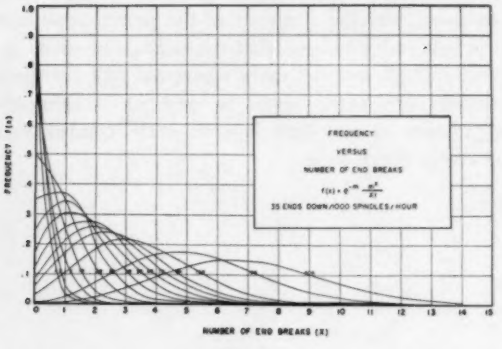

Fig. 1.

End Breakage in Spinning

The Poisson Distribution

When the probability of the occurrence of an event is small and the number of occurrences at given time intervals is independent of any other interval, it can be shown that the probability of x occurrences in a given time interval follows the Poisson distribution, i.e.,

$$f(x) = e^{-m}\frac{m^x}{x!}$$

where m is the true mean number of occurrences of a random event at given time interval and x is the number of occurrences of such event.

In the process of spinning, it may be assumed that practically all the end breakages occur between the nip of the front pair of drafting rolls and the bobbin. If this distance averages 14 in. on a conventional spinning frame with a 1-in. front roll turning 150 r.p.m., there are approximately 20,000 such 14-in. lengths subject to chances of break each 10 spindle hours. Thus in reality, the number of ends down

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 14, 1958.

is small; hence the probability of occurrence of the number of ends down for a given number of spindles would obey the law of the Poisson distribution.

The Frequency of Occurrences of End Breakage

With the use of Poisson frequency function for a given number of spindles, n, the values of the frequency of occurrences $f(x)$ for various numbers of end-breaks x have been computed and tabulated in Table I and are presented graphically in Figures 1 and 2.

Table II lists the values of the cumulative Poisson distribution for various values of n and x using the following form:

$$F(x) = \sum_{i}^{0} e^{-m} \frac{m^x}{x!}$$

Values of x are recorded on the left and values of n are recorded across the top. The numbers in the table are cumulated relative frequency of end breakage values for various numbers of spindles tested. In the process of cumulation, the summation is from

TABLE I. Frequency of Occurrences $f(x)$

n = number of spindles/hr.; x = number of breaks

n	5		10		20		30		40		50	
Ends down/1000 sp./hr.	35	75	35	75	35	75	35	75	35	75	35	75
x												
0	0.84	0.69	0.70	0.47	0.50	0.22	0.35	0.10	0.25	0.05	0.17	0.02
1	0.15	0.25	0.25	0.36	0.35	0.34	0.37	0.24	0.35	0.15	0.30	0.09
2	0.01	0.05	0.04	0.13	0.12	0.25	0.19	0.27	0.24	0.22	0.27	0.17
3		0.01	0.01	0.03	0.03	0.13	0.07	0.20	0.11	0.22	0.16	0.21
4				0.01		0.05	0.02	0.11	0.04	0.17	0.07	0.19
5						0.01		0.05	0.01	0.11	0.02	0.15
6								0.02		0.05	0.01	0.09
7								0.01		0.02		0.05
8										0.01		0.02
9												0.01

n	60		70		80		100		150		200	
Ends down/1000 sp./hr.	35	75	35	75	35	75	35	75	35	75	35	75
x												
0	0.12	0.01	0.09	0.01	0.06	—	0.03	—	0.01	—	0.00	—
1	0.26	0.05	0.21	0.03	0.17	0.02	0.10	0.01	0.03	—	0.01	—
2	0.27	0.11	0.26	0.07	0.24	0.04	0.18	0.02	0.07	—	0.02	—
3	0.19	0.17	0.21	0.13	0.22	0.09	0.22	0.04	0.13	—	0.05	—
4	0.10	0.19	0.13	0.17	0.16	0.14	0.19	0.07	0.17	0.01	0.09	—
5	0.04	0.17	0.06	0.17	0.09	0.16	0.13	0.11	0.17	0.02	0.13	—
6	0.02	0.13	0.03	0.15	0.04	0.16	0.08	0.14	0.15	0.04	0.15	0.01
7		0.08	0.01	0.12	0.02	0.14	0.04	0.15	0.11	0.06	0.15	0.01
8		0.05		0.08		0.10	0.02	0.14	0.08	0.08	0.13	0.02
9		0.02		0.04		0.07	0.01	0.11	0.04	0.10	0.10	0.03
10		0.01		0.02		0.04		0.08	0.02	0.12	0.07	0.05
11		0.01		0.01		0.02		0.06	0.01	0.12	0.05	0.07
12						0.01		0.04	0.01	0.11	0.03	0.08
13						0.01		0.02		0.10	0.01	0.10
14								0.01		0.08	0.01	0.10
15										0.06		0.10
16										0.04		0.10
17										0.03		0.08
18										0.02		0.07
19										0.01		0.06
20												0.04
21												0.03
22												0.02
23												0.01
24												0.01
25												0.01

$i = x, x-1, \cdots 0$. Figures 3 and 4 exhibit the plot of $F(x)$ versus x for various numbers of spindles for 35 and 75 end breaks/1000 spindles/hr.

The Critical Values

An end breakage rate as high as 35 breaks/1000 spindles/hr. is considered acceptable by many spinning mills. An end breakage rate between 35 and 75/1000 spindles/hr. may be considered to be fair for some work. Beyond 75 ends down/1000 spindles/hr. would produce unsatisfactory spinning.

The critical values c are defined as the number of ends down for given number of spindles/hr., which satisfies the following condition:

$$F(c) = \sum_{c}^{0} e^{-m} \frac{m^c}{c!} = 0.95$$

Hence

$$F(x > c) = 1 - \sum_{c}^{0} e^{-m} \frac{m^c}{c!} = 0.05$$

The critical values for various n for 35 and 75

TABLE II. Cumulative Frequency of Occurrence $F(x)$

n = number of spindles/hr.; x = number of breaks

n	5		10		20		30		40		50	
Ends down/1000 sp./hr.	35	75	35	75	35	75	35	75	35	75	35	75
x												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0.16	0.31	0.30	0.53	0.50	0.78	0.65	0.90	0.75	0.95	0.83	0.98
2	0.01	0.06	0.05	0.17	0.15	0.44	0.28	0.66	0.40	0.80	0.53	0.89
3		0.01	0.01	0.04	0.03	0.19	0.09	0.39	0.16	0.58	0.26	0.72
4				0.01		0.06	0.02	0.19	0.05	0.36	0.10	0.51
5						0.01		0.08	0.01	0.19	0.03	0.32
6								0.03		0.08	0.01	0.17
7								0.01		0.03		0.08
8										0.01		0.03
9												0.01

n	60		70		80		100		150		200	
Ends down/1000 sp./hr.	35	75	35	75	35	75	35	75	35	75	35	75
x												
0	1.00	1.00	1.00	1.00	1.00	1.00	1.09	1.00	1.00	1.00	1.00	1.00
1	0.88	0.99	0.91	0.99	0.94	1.00	0.97	1.00	0.99	1.00	1.00	1.00
2	0.62	0.94	0.70	0.96	0.77	0.98	0.87	0.99	0.96	1.00	0.99	1.00
3	0.35	0.83	0.44	0.89	0.53	0.94	0.69	0.96	0.89	1.00	0.97	1.00
4	0.16	0.66	0.23	0.76	0.31	0.85	0.47	0.90	0.76	1.00	0.92	1.00
5	0.06	0.47	0.10	0.59	0.15	0.71	0.28	0.80	0.59	0.99	0.83	1.00
6	0.02	0.30	0.04	0.42	0.06	0.55	0.15	0.66	0.42	0.97	0.70	1.00
7		0.17	0.01	0.27	0.02	0.39	0.07	0.51	0.27	0.93	0.55	0.99
8		0.09		0.15		0.25	0.03	0.36	0.16	0.87	0.40	0.98
9		0.04		0.07		0.15	0.01	0.23	0.08	0.79	0.27	0.96
10		0.02		0.03		0.08		0.14	0.04	0.69	0.17	0.93
11		0.01		0.01		0.04		0.08	0.02	0.57	0.10	0.88
12						0.02		0.04	0.01	0.45	0.05	0.81
13						0.01		0.02		0.34	0.02	0.73
14								0.01		0.24	0.01	0.63
15										0.16		0.53
16										0.10		0.43
17										0.06		0.33
18										0.03		0.25
19										0.01		0.18
20												0.12
21												0.08
22												0.05
23												0.03
24												0.02
25												0.01

ends down/1000 spindles/hr. can be determined graphically from Figures 3 and 4, and are presented in Table III.

These critical values can be used as a guide to judge spinning performance. The sum of the probability of occurrences of x number ends down which is greater than the critical value c for given n under the null hypothesis is approximately 0.05. Hence in the observation, if a value x obtained is greater than c, the predetermined critical values for given n, then if the null hypothesis (assuming $H_0 = 35$ ends down/1000 spindles/hr.) is really true, the chances of getting a sample result such as the observed are only about 5 in 100. This would indicate that the null hypothesis is not true.

For example, suppose an experimenter was observing the number of ends down/50 spindles/hr. If at the end of the period, he obtained a result of 8 ends down, which exceeds the critical value of 4.7 for 35 ends down/1000 spindles/hr., it may be concluded that in actual mill running condition he would get an average number of ends down higher than 35/1000 spindles/hr.

For a rapid evaluation of end breakage, the critical values for various values of n for the two levels of ends down/1000 spindles/hr., 35 and 75, have been plotted against the number of spindle hours in Figure 5. Three regions good, fair, and poor have been designated according to less than 35, between 35 and

TABLE III. The Critical Values of Breaks

No. of spindles, n	Breaks	
	35 ends down 1000 spindles/hr.	75 ends down 1000 spindles/hr.
10	2.0	2.9
20	2.7	4.2
30	3.4	5.4
40	4.1	6.6
50	4.7	7.6
60	5.2	8.8
70	5.8	9.6
80	6.3	10.7
100	7.3	12.6
150	9.7	17.3
200	12.0	21.8

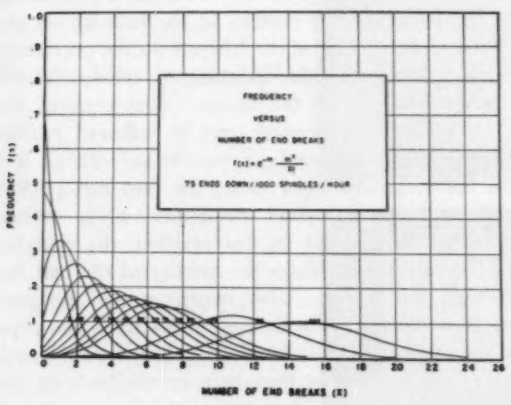

Fig. 2.

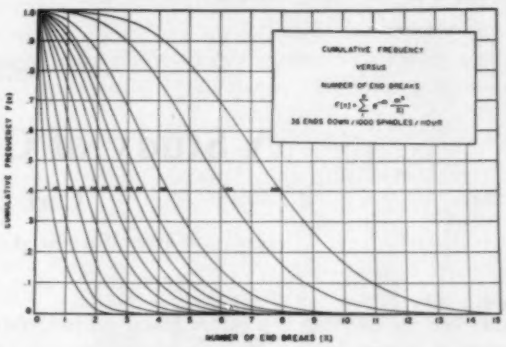

Fig. 3.

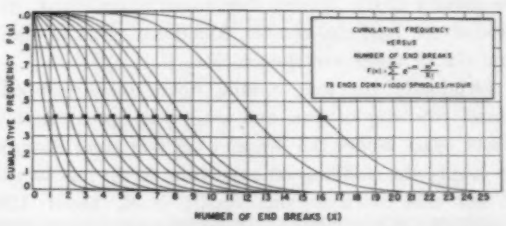

Fig. 4.

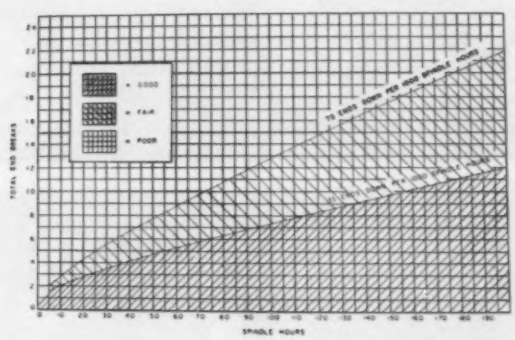

Fig. 5. Ends down rating chart, using arbitrary end-breaking levels of 35 and 75 ends down per 1000 spindle hours.

75, and greater than 75 ends down/1000 spindles/hr. This chart, copies of which are available, can be used by laboratories in predicting the ends down performance in large-scale spinning from results obtained on a limited number of spindles.

Experimentation

It is not the scope of this paper to elaborate on the experimental design and technique for making end breakage tests; however, there are data available [1, 2, 4, 5] for those interested in this area.

Acknowledgments

The author is indebted to Professor J. F. Bogdan and Dr. R. J. Hader of North Carolina State College for their valuable suggestions.

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A Study of Cotton Combing[1]

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COTTON combing is a rather broad subject; this paper is a very brief discussion of some points of common interest. The background and the general mechanics of the process are sketchily reviewed; included are how the comber functions, what it does, and the economics of the process.

Originally the long textile fibers were combed. Hand combing of flax and wool was practiced for many years before the demand became great enough to justify the building of a machine to do this work. When this machine was finally built, about 100 years ago, it was found that it would also handle short staple; thus cotton combing had its birth. Here again, as with the cotton card, the inventor worked too well and gave mankind a machine that is basically the same today as it was then. True, many mechanical improvements have been made and production has increased many fold; however, the basic principles and method of operation remain unchanged.

The process of combing, along with the comber itself, still remains the nicest and most intricate operation in the manufacture of yarn. When one considers that a continuous sheet of cotton is broken, fibers are held and combed at each end while short staple and trash are removed, and the clean straight fibers are reassembled into a continuous uniform sliver, one can well picture the mechanical difficulties encountered in the construction of a machine that will perform this cycle 150 times each minute. Along with this nicety of construction must be durability, the capacity to run 24 hours a day year in and year out with a minimum of attention and stoppage.

The actual operation of combing consists of a series of intermittent motions: the feeding and gripping of the sheet or lap of cotton, the combing of the fringe by the needles of the half lap on the cylinder, the joining of the fringe with the previously combed fibers, and the detaching or removal of the combed fibers from the fringe. The path of the stock through the comber can be followed readily by referring to Figure 1. From the lap rolls (L.R.) the cotton passes down under the feed roll (F.R.) and projects out beyond the nippers (N). While the stock is clamped in this position, the cylinder (C) revolves and brings the needles of the half lap through the fringe. This needle section removes the short fiber along with most of the trash and neps in the original stock. A revolving brush, not shown, clears the needles as they turn to the back of the machine; this noil is then collected in an air stream

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 12, 1958.

and deposited on a slowly turning perforated drum. The combing cycle is completed when the detaching rolls (D.R.), by their controlled motion, carry away the fibers that are then reassembled to form the combed sliver.

When the comber is running, the nippers swing in a path from directly in back of the detaching rolls to a point well beyond the center of the cylinder shaft. The amount of noil removed is determined by three adjustments: the distance between the bite of the detaching rolls and the nose of the nipper assembly, the closeness to which the nippers approach the needles of the half lap, and the position or adjustment of the top comb. Depending somewhat upon the character of the cotton, it should be quite possible to vary the percent of noil removed from 5% to perhaps 30%.

Another factor that has come to the fore recently is the effect of lap weight upon the amount of noil removed. Over a period of time there has been a rather steady increase in the weight of laps prepared for combing, until today a weight three or four times that of the early years is quite common. If high production rates are to be attained, it becomes necessary to use a rather heavy lap. With the old conventional type of lap preparation, an increase in lap weight requires a reduction in the draft at some point along the line. This results in less straightening of the fiber; therefore a greater load is thrown upon the comber. Just what effect this has upon the action of the comber is clearly indicated by the results of a simple test. A comber was set up to remove 16% noil from a lap weighing 800 gr./yd. Then, with no mechanical readjustment whatever, these laps were replaced by others weighing 900 and 1200 gr./yd.; the results were as follows:

16.0% noil from 800-gr. laps
17.8% noil from 900-gr. laps
20.8% noil from 1200-gr. laps

It is evident that it is much more difficult to comb a heavy lap than one of lesser weight.

Figures 2 and 3 are reproductions of actual staple diagrams drawn from samples of stock used for test purposes. Two sets are included: one represents a typical long staple while the other is a rather common commercial $1\frac{1}{8}$-in. staple. Of course, the aim

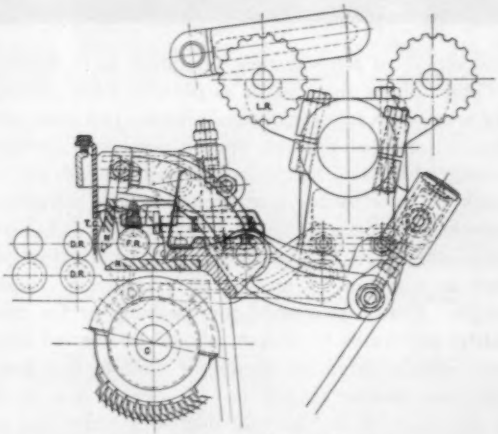

Fig. 1. Nipper frame details.

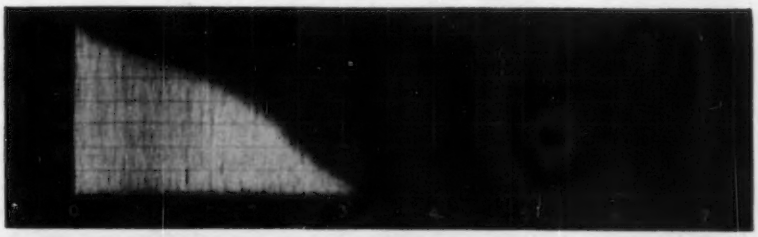

Fig. 2A. Ribbon lap (1); 12/57.

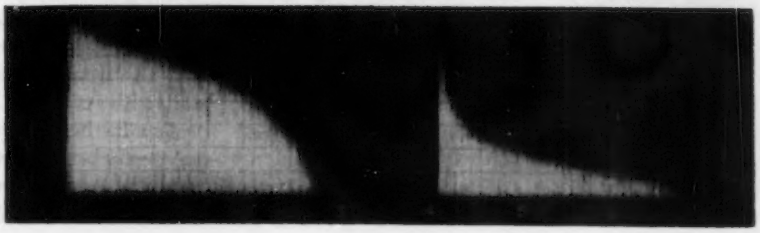

Fig. 2B. Combed sliver (1); 13% noil.

Fig. 3A. Ribbon lap (2); 12/57.

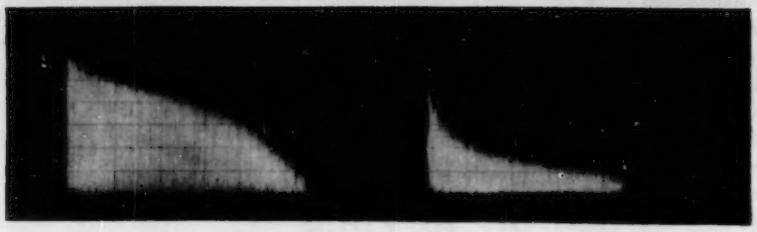

Fig. 3B. Combed sliver (2); 9.5% noil.

and object of any combing operation is to remove as much of the short staple as possible while passing the long fibers into the combed sliver. Just how well that can be done depends upon a number of factors, among which are the mechanical construction of the machine, its adjustment or timing, type of lap preparation, and character of the cotton staple. It is very interesting to see the wide range of fiber distribution that is common to any given commercial staple length. Cotton purchased for combing, or for that matter any cotton to be spun, should be selected with care; special attention should be paid to that part that runs shorter than $\frac{3}{4}$ in. If 20% of the stock is less than $\frac{3}{4}$ in., it will require a magician to remove only 14% at the comb and still do a good job of combing. Likewise, there are times when a mill will remove a high percent of noil needlessly. Many mills do not exercise sufficient care in choice of staple and in adjusting the combing operation to suit their stock.

Another point of interest is demonstrated by the diagrams of the noil. It will be noticed that there are present a few fibers equal in length to the longest present in the comber lap. The rate of drop in length should be very rapid at this end of the diagram, but it is practically impossible to obtain a diagram with no long fibers whatever. With improved lap preparation it is possible to keep these at a minimum, because hooked or nonparallel fibers are the chief cause of this condition. When a comber is operating efficiently, the average length of the noil should not exceed approximately 0.45 in. There are times, however, when this will be exceeded, notably when running long staple cotton with a high percent of noil.

As a means of representing graphically exactly what happens at the comb, Figure 4 is constructed as a composite of a series of staple diagrams reduced to a common scale. This graph shows clearly what changes take place when combing is introduced into the series of operations normally employed in spinning. The individual curves serve a number of purposes, but one is to determine the so-called "effective staple length." If a reading is taken at one third the base length starting from the left, one obtains a value that represents comparatively the spinning capacity of the sample. Taking these readings from Figure 4, the following results are obtained:

Noil	0.40
Card sliver	0.97
Comber lap	1.02
Combed sliver	1.12

In this particular case, it means that the spinning capacity is increased by the equivalence of $\frac{1}{10}$ in. Normally combing is considered to add at least $\frac{1}{8}$ in. to the spinning value of any cotton. One will also note that the operations employed in lap preparation will add somewhat to the staple length due to the drafting and straightening of the fibers.

To complete this part of the story, the stock used in this test was carried through spinning. Table I will allow comparison and judgment of the benefits derived by combing.

As a further point of interest, Figure 5 shows what happens when the percent of noil is varied. As the combing becomes more thorough (percent of noil increased), one will note that the average staple

length increases while the neps passed into the combed sliver decrease in number. In other words, some choice must be made, and this will have to be based on the quality required in the end product and cost of the operation.

In any business where the difference between a profit and a loss might be represented by the difference of a fraction of a cent per yard of goods in the cost of manufacture, only the most efficient and the least costly processes can be employed. With this in mind it might be well to judge combing from this standpoint. A summary would include the following items:

Benefits

1. Increased break factor, approximately 10%
2. Increased effective staple length, about 12%
3. Improved yarn appearance, one grade or more
4. More even yarn
5. Yarn with more luster
6. Higher spinning limit, finer yarn
7. Less ends down in spinning
8. Yarn may be spun with less twist
9. Higher drafting capacity

Costs

1. Direct labor—about 1¢/lb.; overhead—about 1¢/lb.
2. Material removed when running 14% noil—about 2¢/lb. if the noil can be sold at 60% of the raw cotton price.
3. Machine investment—approximately $250/lb./hr. to be combed.
4. Additional floor space—about 7 sq. ft./lb./hr.

In order to convert these factors into dollars and cents, a table of relative prices of cotton, delivered in New England as of January 1958, follows:

Grade	Staple Length 1 in.	1 1/16 in.	1 1/8 in.	1 3/16 in.
Strict Middling	38.25	40.25	42.65	44.75
Middling	37.55	39.30	40.75	42.75
Strict Low Middling	34.60	36.85	38.45	39.50

Waste Prices		
Comber Noil	Peeler	23.75
	Egyptian	21.00
Card Strips	Brush	24.50
	Vacuum	21.50

If combing will increase effective staple length by 1/8 in. and appearance by one grade, just what will that mean in value? From the table assume that Mid 1 1/16 in. at 39.30¢/lb. is combed. At the spinning frame this becomes the equivalent of Strict Mid. 1 3/16 in. which is worth 44.75¢/lb., or a difference of 5.45¢/lb. This difference will more than pay for the increased labor cost and the loss due to noil. It is quite true that the waste in processes up to combing will be increased as one lowers the starting grade, but this additional cost still will not bridge the gap between 4¢ and 5.45¢.

For that matter, the simple difference in the value of tare becomes quite an item if production is 400 lb./hr. Normally 24 lb./bale is allowed for bagging and ties; if the difference in cotton price is 5.45¢/lb. this means an extra $1.30/bale. At the end of a year this alone will just about pay for one comber.

With the increased mechanization of cotton production and the consequent lowering of staple length and quality, it becomes more and more difficult for mills to obtain stock of satisfactory character. The premium to be paid for the better grades and staples will increase as time goes on. As a result, combing will become increasingly important as a means of raising the spinnability of some of these poorer stocks to a level that will meet mill requirements.

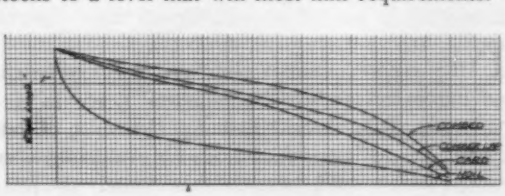

Fig. 4. Effect of combing on staple distribution; 1 in. staple, 15% noils.

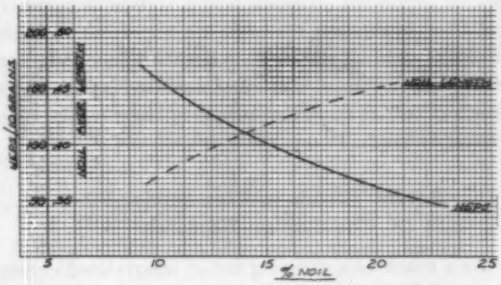

Fig. 5. Effect of varying noil percentage.

TABLE I. Effect of Combing

		Carded	Combed
Sliver	Uster average	12.6	17.8
	Uster deviation	2.4	3.1
Finisher drawing	Uster average	16.6	13.2
	Uster deviation	3.2	2.5
Roving 1.00 hank	Uster average	22.0	19.2
	Uster deviation	4.3	3.0
Yarn 30s	Uster average	98.0	67.0
	Uster deviation	18.3	12.3
	Break factor	2180	2560

In times past when combing was a slow and expensive process, limited more or less to the production of the finer costly yarns, its field of use was rather restricted. Today conditions are quite different. It would be well for many mills to explore the possibility of including combing as a part of the spinning process. Just to add combing and hope to increase the selling price of the final product to offset the increased cost is not enough. Careful evaluation of all the advantages gained must be the basis of the final conclusions. Since no two mills are exactly alike, each will have to make its own appraisal and come to its own conclusions. It is not a difficult problem and the results might be most interesting.

Manufacturing Performance and the Evaluation of Fiber Quality[1]

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THIS report encompasses three very important and urgent research and commercial needs in cotton—research on manufacturing performance of lint, research on commercial methods for evaluating fiber quality, and research to establish accurately the relationships between commercially measured fiber quality and manufacturing performance. Brief reports will be presented on some recent trends in commercial fiber evaluation research, an experiment on the effects of ginning methods on the manufacturing performance of cotton, and recommendations to cotton breeders as to the fiber property they might most profitably study.

Recent Trends in Commercial Fiber Evaluation Research

As a result of a growing list of interrelated causes, the need for better fiber testing methods has become urgent. Some of the factors bringing this need into its present sharp focus are:

1. The value of laboratory and commercial fiber tests in the control of yarn quality, and to a lesser extent of fabric quality, has been demonstrated.

2. By means of cooperative mill tests of several kinds, more and more proof accumulated that there are very definite, very important, but at the same time very subtle relationships between fiber properties and manufacturing performance. Although it was long ago known that relatively "gross" fiber properties affected mill operations, special efforts are now being made to prove beyond doubt that the presently subtle relationships are or are not important.

3. Simultaneous revolutions in cotton breeding, growing, harvesting, ginning, and spinning are proceeding at breakneck pace. These revolutions have brought most or all the old criteria of fiber quality and of acceptable manufacturing performance under severe questioning. Therefore, it becomes imperative that these criticisms be judged by the use of improved fiber evaluation methods, and that the quality of cotton be improved and better preserved where indicated.

Last year, as a result of these events, the spinners' delegation to the National Cotton Council recommended that a full-scale cooperative inquiry be made into the spinning quality of American cotton, with particular attention being given to the relationships of modern cotton varieties; fertilization, irrigation, and harvesting practices; ginning procedures; and bale handling methods to the manufacturing performance of the cotton.

Cooperative work was started, its first accomplishment being an analysis showing that the revolution in the cotton industry demanded better and faster

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 13, 1958.

commercial fiber testing methods so that the effects of all processes from breeding to manufacturing could be measured; the establishment of a pilot plant spinning mill to study the effects of fiber quality on manufacturing performance; and a series, extending over several years, of ginning-spinning tests to determine as rapidly as possible the effects of ginning processes on manufacturing performance.

The Cotton and Cottonseed Research and Marketing Advisory Committee (CCRMAC) then recommended that the USDA study the feasibility of establishing a pilot cotton textile plant. The range of the recommended study can best be shown by reading the resolution in full, as follows:

> The Cotton and Cottonseed Research and Marketing Advisory Committee recommends:
>
> 1. That the USDA undertake a thorough study and analysis of the need for and feasibility of establishing a commercial scale pilot cotton spinning, weaving, and knitting mill and finishing plant, with special emphasis on
>   (a) Cost of establishing and operating the facility.
>   (b) Its usefulness in establishing ways for measuring the true market value of cotton.
>   (c) Its usefulness in commercial scale testing of the results of research and development coming from all phases of production, marketing and utilization.
>   (d) The possibility of meeting the need through better coordination of existing facilities, including the textile schools, textile research institutes, USDA spinning laboratories, SURDD, and private facilities, etc.
> 2. That the study specifically exclude any consideration at this time of the place of such a facility in the USDA organization for administration.
> 3. That the composition of the study group include all interested segments of the cotton industry but especially representatives of the textile mills.
> 4. That the study group report its findings to the CCRMAC (Cotton and Cottonseed Research and Marketing Advisory Committee) at its next meeting, in Washington, D. C., February 26–28, 1958.

The Department immediately appointed a committee of its high officials and of outstanding leaders in the cotton industry to make the study.

From the outset, it was realized that many persons would have to assist the Study Committee if an authoritative study were to be made. These people will present a report to CCRMAC at the end of February, 1958.

The Study Group will have in its hands a large body of organized materials upon which it can base its findings and report to CCRMAC. These organized materials cover such items as

1. an evaluation of existing methods for determining the true spinning value of cotton,
2. specific sugestions on lines of fiber research and on what organization and coordination is necessary for an effective fiber research program,
3. an evaluation of the contribution of conventional cotton classing to the operations of modern cotton merchandising and manufacturing,
4. a catalog of services offered by the USDA for the evaluation of cotton quality and how they are coordinated with other cotton research and services,
5. an evaluation of modern methods of cotton harvesting, ginning, and handling and their effects on fiber quality,
6. an estimate of the extent to which present research programs can be accelerated promptly through better coordination in the use of facilities in textile schools, research institutes, USDA cotton laboratories, and private facilities,
7. a catalog of the usefulness and availability of present spinning test facilities for these problems, and
8. an estimate of additional pilot plant facilities needed for large scale testing, including an estimate of the capital and operating costs of any recommended facility.

This then brings up to date the history of recent efforts to increase research on the commercial evaluation of fiber quality, with special reference to the relation of fiber quality to manufacturing performance.

The Effects Of Ginning Methods on Fiber Quality and Manufacturing Performance

A cooperative ginning-spinning test is being conducted in which 12 combinations of seed cotton drying, seed cotton cleaning, and lint cleaning are being related to fiber quality, manufacturing performance, and product quality. The ginning conditions being studied are shown in Table I.

Two amounts of seed cotton or overhead cleaning were used. For each amount of overhead cleaning, two degrees of drying were employed in an attempt to bring the lint to either a 5–6% or to a 2.5–3% moisture content. For each degree of drying, the cotton either bypassed the lint cleaners, or passed

TABLE I. Ginning Phase

Amount of overhead cleaning			
Moderate		Elaborate	
Degree of drying, %			
Moderate	High	Moderate	High
5–6	2.5–3	5–6	2.5–3
Number of lint cleaners used			
0	0	0	0
1	1	1	1
2	2	2	2

TABLE II. Summation of Samples—Through Spinning

Samples for:	No. of samples
Trash content (seed cotton)	96
Shirley	108
Moisture content	240
Classing	384
Fibrograph (regular and dial)	576
Causticaire	288
Suter-Webb	288
Tenacity (0 and $\frac{1}{8}$ in. gauge)	576
Spinning (small sample)	36
Spinning (mill)	12

through one lint cleaner, or was processed through tandem lint cleaners. Four bales were ginned under each of these 12 conditions. The cotton was machine picked from one field on a single day. Very generous samples are being retained from each step in ginning and manufacturing.

Table II shows the number of samples into which the seed cotton and/or the lint cotton have been divided, including the 36 samples which will be spun at Clemson and the 12 four-bale samples which will be spun by Joanna Mills this spring. It is clearly seen that the experiment is under control, and that any changes in fiber properties can be followed at each step in the ginning process. To these tests will be added a complete set of tests to follow the progress of the cotton through manufacturing and to evaluate intermediate and final products.

In addition to the immediate objectives of the test, it is expected that supplemental information will be gained. For example, it is planned to establish a "base line" description of cotton qualities acceptable for economic manufacturing performance. Naturally, several ginning-spinning tests will be necessary before the base line is fully established. All the fiber and manufacturing performance data gathered over several years will be used to fix the base line description of acceptable cotton. Farmers, ginners, and merchants will find the base line fully as useful as it will be to spinners.

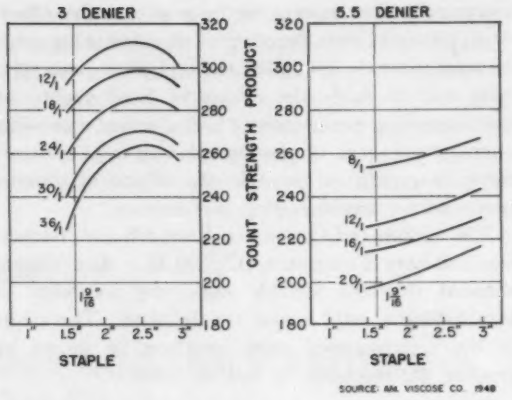

Fig. 1. Effect of staple on single end yarn construction.

Another supplemental use of this ginning-spinning test is illustrated in the use of the dial Fibrograph. This test presents an opportunity to evaluate dial Fibrograph measurements against other data and to see if the additional data from the modified instrument are useful in explaining manufacturing performance and product quality. The large fiber samples being retained can be used in a similar fashion by others to evaluate the fiber testing methods they are developing.

In conclusion, then, a carefully planned ginning-spinning test of manageable size, involving one variety of cotton, one gin, and one mill, is now in progress.

Effect of Fiber Length

All knowledge of cotton, especially that of fiber properties and spinning performance, helps guide the breeder. For example, the Textile Research Institute's cotton project, supported by certain mills and by contract funds from the USDA, has as a main objective the development of data useful to the breeding program. The Spinner-Breeder Conferences sponsored by the Delta Council for a number of years brought spinners and breeders together to discuss mutual problems and seek specific guides for the breeders. A specific recommendation has now been formulated and transmitted to the breeders in a talk given at their annual Cotton Improvement Conference, held this past winter in Memphis.

Because *spinners* are directly concerned with the quality bred into cotton fiber, the substance of the recommendation and the supporting argument to the breeders that the property of fiber length, in all its aspects, should be studied by breeders is given here. If their study confirms the argument given, then they should proceed to improve fiber length quality. The breeders were told the following:

Enough is now known about length, its measurement, and its relation to manufacturing performance to justify the recommendation that breeders consider putting added stress on length in breeding programs. Length should not be defined merely as staple or upper half mean length. All the factors that go to make up the pattern of length must be considered. For example, it might well be that the reduction of short fibers is more important than a simple increase in staple.

There are strong correlations between fiber properties, making it difficult to separate out the contribution of length to yarn quality or spinning efficiency. A clearcut case of how length contributes to yarn strength is shown in Figure 1—an experiment with rayon. With denier, and presumably strength, being held constant, yarn strength goes up with increased staple in all cases

In the rayon 24s yarn, a $\frac{1}{2}$-in. increase in staple causes less than 7% increase in yarn strength over the base of 260 count-strength units. One can hardly talk in terms of $\frac{1}{2}$-in. increases in staple in one variety. But by increasing the $1\frac{1}{2}$-in. staple in a 24s cotton yarn by only $\frac{1}{8}$-in., yarn strength was increased 12.6% as contrasted to only 7% with a $\frac{1}{2}$-in. staple increase in rayon. In short, length and the factors that make up length, plus the fiber properties correlated with length, exert a powerful force on cotton yarn quality and operations. The spinner takes advantage of this fact when he combs cotton to manipulate the factors in the length pattern.

There is a marketing argument for the importance of length, as shown in Figure 2. The disappearance of 1-in. and shorter cottons has decreased, as shown by the general reduction in the size of those blocks, in the past 20 years. In the same period the blocks representing the use of $1\frac{1}{32}$-in. and longer cottons increased in size.

This situation is shown more strikingly in Figure 3, in which the data just examined are put on a percentage basis. About 20 years ago, 1-in. and shorter cotton accounted for 65% of the cotton spun. Today, they account for about 35% of the total disappearance. In the meantime, $1\frac{1}{32}$-in. and longer cottons have filled the gap, and have exactly reversed the situation of 20 years ago when they accounted for 35% of cotton spun; today they account for 65%.

This can mean only, based on staple, that modern spinning, modern fabrics, and modern taste demand longer cottons. This does not necessarily mean that all staples should be raised $\frac{1}{16}$-in. or some other amount, but it does mean that length and length factors are important in the market. It means that spinners and consumers, being the demand half of the famous supply and demand twins, force the supply half to look at length in relation to consumption in markets.

Efficient manufacturing performance demands that length factors be adapted to modern manufacturing methods. Production executives of mills representing well over 1,000,000 spindles were asked what had happened to spinning in their plants since World War II. This survey showed that:

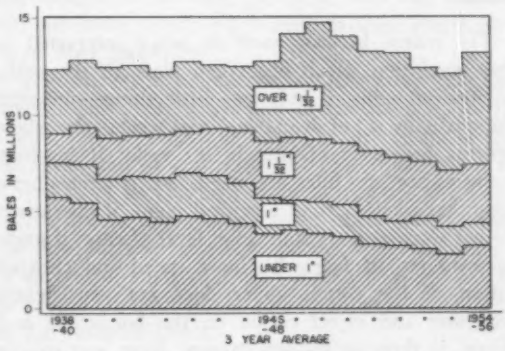

Fig. 2. Millions of bales disappearance U. S. cotton by staple.

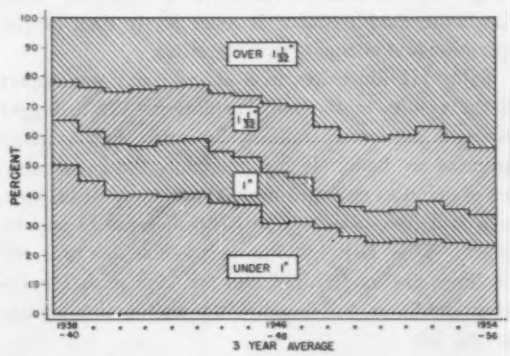

Fig. 3. Percent disappearance U. S. cotton by staple.

1. Each mill had modernized its machinery, processing organization, maintenance program, and atmospheric control.

2. Each mill increased spindle and front roll speeds and package sizes.

3. Each mill increased spindle assignment 50% to 300% per spinner by eliminating most of her cleaning tasks and by better maintenance of machines.

4. Each mill is working closer and closer to the spinning limits of its cotton, but it is trying to be more selective in its cotton buying.

5. Variations in ends down are no greater than they were at the end of the war.

6. To the question, "Of all fiber properties, which is in most need of improvement?" each mill man answered without hesitation, "Length." Each man had some pretty definite ideas as to what was needed in length factors and what the necessity was for better ways to measure length. Probably never before this survey have the mills given breeders such a clearcut statement of their specific fiber quality needs.

The cotton breeder must be much interested in this revolution which has taken place in the mills. In modern mills, if only one little thing—and that thing usually is not definable—goes wrong, the whole process begins to operate in the red. If machine maintenance schedules are neglected, if atmospheric conditions drift beyond a critical point, if operatives do not work at a constant high level of care, if management tempts fate with more speed and cheaper cotton, if the cotton buyer does not consistently recognize and reject cotton on the borderline and lower, if there is hidden damage from any source such as weathering or poor ginning—if any of these things happen, then processing costs can rise. They rise because added labor is more costly than proper operation and adequate raw materials.

Table III illustrates in a specific way one aspect of the results of the mill revolution. While bigger packages put extra strain on the cotton, half as many spinners are handling approximately the same number of spindles and turning out more pounds of yarn, even if it is assumed there is no increase in spindle speed. This labor saving is possible because the machines are modernized and are kept in A-1 operating condition and because the cotton is adequate for the job.

Another type of mill change is analyzed in Table IV. This again is but one aspect of the total revolution in the mills. At the war's end, the spinner had to do all these jobs. It took so many minutes (Column 2) to do each of the tasks named in Column 1 on one frame side. These tasks were done so many times each week on one frame side (Column 3). The last column shows the minutes used to operate one side one week—a total of 207¾ min. Because the spinner had an assignment of 10.4 sides, she therefore worked 36 hr. a week, leaving her 10% personal time.

When the spinner's assignment was modernized, all of the time-consuming cleaning work was handled by other means. The spinning jobs proper plus the two minor cleaning jobs are now 93 min./side/week. With a new assignment of 23.2 sides, she still works 36 hr. a week. Her spindle assignment has

TABLE III. Spinning in a 1950 vs. 1957 Cotton Mill

	Warp		Filling	
	1950	1957	1950	1957
Gauge, in.	3	3¼	2⅞	3¼
Ring, in.	1⅝	2	1⅜	1⅝
Traverse, in.	6½	9	6	7
Number of spindles	18,944	18,260	8,640	7,100
	1950		1957	
Number of spinners	17/shift		8/shift	

Source: Am. Tex. Mach. Assoc.

TABLE IV. Time Required for Mill Operations

	Min./ task	Times/ week	Min./ week
Brush and clean rings	1.50	4	6.00
Passing board	.35	20	7.00
Clean:			
Side rails	.25	40	10.00
Beam and bottom creel	4.50	5	22.50
Middle creel	1.50	10	15.00
Frame and top creel	.75	5	3.75
Top front rolls	11.00	2	22.00
Middle rolls	7.00	1	7.00
Back rolls	7.00	1	7.00
Pick:			
Under clearers	30.00	.25	7.50
Rotary clearers	20.00	1	20.00
Creel roving	.33+	133	44.00
Piece up ends	.30	120	36.00
Total—93 min.		Total	207.75

With cleaning—10.4; modern load—23.2 sides

Source: Textile Industries, Aug. '57

increased by more than 100% (actually, according to the source, from 1248 to 2784 spindles).

This is a simple case, not complicated by changes in package sizes, changes in speeds, nor modernization so that the machine could do better work. Apparently these frames just plodded along at the same old rate. But even this simple change can result in much trouble if something goes wrong.

Assume, under the old conditions, her assignment is 1000 spindle hr./hr., and under the modern conditions, the assignment is 2000 spindles—round numbers to make the calculation simple. The ends down in this illustration compute to 25/1000 spindle hr. under both the old and modern assignments. Assume that something increases ends down by 20%. This would be an increase of 5 ends—an increase of exactly 1½ min. of work each hour until the trouble is straightened out. But she has the cushion of all this cleaning time to absorb the 1½ min. extra work. If, on her modern job, she has the same 20% increase in ends down, she has 10 extra ends to piece up each hour, or 3 min. extra work, and not nearly enough cushion in her minor cleaning jobs to absorb the extra work.

All this means trouble—and lots of it. In short, the modern spinning organization is exceedingly sensitive to any deviation from the ideal performance of machine, atmosphere, spinner, cotton buyer, and cotton. The breeder must particularly judge his product on the basis of its relation to costs of manufacturing such as shown in the illustrations just given.

Costs of manufacturing seem to be related mostly to the factors of length. Therefore, breeders should study length. This does not mean that other fiber properties and yields are to be sacrificed to length. The breeder has much work to do and many experiments to perform before he finally decides to what degree he will stress length in his breeding program.

In order for the breeder to improve fiber properties effectively, the following things are necessary: accurate information from the manufacturer as to just what is required to meet mill performance standards; better and faster fiber testing methods and also cheaper and more rapid tests of manufacturing performance and product quality; a more thorough study of his cottons (this means he must know more about the fiber while it is still on the seed so that he can better separate inherent fiber quality from qualities modified by weather, harvesting, ginning, and spinning.); an ever closer cooperation among breeder, farmer, ginner, and spinner, in order to measure the suspected "cumulative effect" of growing and processing operations on fiber quality; and an improved team effort among breeder, agronomist, and plant physiologist to increase yields so that the breeder can put more selective pressure on fiber length and other fiber properties.

The successful completion of his study will tell breeder and spinner whether or not to increase the staple, improve length uniformity, work on the shortest fibers and otherwise let the uniformity stand as it now is, or let cottons remain as they are and work with growers and ginners to do their jobs so that the inherent fiber length properties are not changed. A successful study of length should help put length in proper perspective—in proper balance—with total cotton research needs.

Spinning Tests for Predicting Yarn and Fabric Quality as a Routine in a Cotton Spinning Mill[1]

Harry Brasseur

Filatures Nouvelle Orleans, Ghent, Belgium

BELGIAN cotton spinners having the privilege of using cotton of all the productive countries of the world face difficult problems in deciding if the cotton of one country may replace another or in what proportion to blend different cottons to obtain a given result. Moreover they seldom buy with a rejection clause and must keep and use every bale the shippers ship them. Therefore, it is imperative that they know how the cottons will behave in processing and how they will turn out in fabrics.

In our mill, we have found that the use of modern testing instruments fails to give us sufficiently precise information for our use in determining whether a cotton of new origin, of which we have many offered to us each year, will meet our requirements. Even when we receive cottons the origin of which we are familiar, neither visual inspection nor the use of measuring instruments will enable us to ascertain if a same grade will correlate with the same aspect of yarn and fabric. For example, it will be shown that Acala 4-42, of which we use about 10,000 bales a year, has been altered in the last four years, so that although the grade is being improved year by year, the appearance of the yarn and of the fabric has suffered a degradation. No instrument would have been able to detect this.

[1] Presented at the Cotton Research Clinic of the National Cotton Council of America, Pinehurst, N. C., February 13, 1958.

TABLE I. Measured Characteristics

Raw cotton	Micronaire (measured on 10% of the bales) Grade and staple (commercial grading) Non-lint content (Shirley Analyzer) Staple length (practical spinning length) Neps (card web content)	
Yarn	Strength (skein test) Appearance (ASTM)	
Fabric	Color Appearance (trash content)	by comparison with home-made standards

In view of the complexity of the problem we decided to test our cotton by direct spinning, submitting indiscriminately to it every lot that enters our spinning mills. To this end we established a pilot plant equipped with regular cotton machinery, the only difference being that the roving and spinning frames have only a small number of spindles.

Procedures

The samples drawn from each bale of a 100-bale (or less) lot are classed by a professional classer, whose judgment is recorded on a card. The samples are then brought to the mill, where they are inspected by the managing director with the help of the technical manager; they draw a provisional conclusion, recorded on the card as excellent, very good, good, fair, bad, or very bad.

The tests are established to get as close as possible to the end use—the fabric. After obtaining the Micronaire figure and the Shirley Analyser trash content, we spin the samples in the pilot plant and knit a piece of tubular knit. This presupposes that the lot is even-running. If not, it is divided into different sublots, which are tested separately.

About half of each of the 100 samples are mixed thoroughly in a hopper feeder transformed for that purpose.

There are no pickers; the card is fed by hand on a feed lattice, equal weights of cotton being spread between equidistant lines painted on the lattice. During the carding operation, the neps in the card web are counted. The "spinning length" of the fibers is measured on the "Litty" experimental spinning machine "Distanceur."

After carding, three passages of drawing and one of roving frame, 36 cotton count is spun from hank roving 2.- on a Casablanca spinning frame.

A first set of 12 bobbins is spun with a twist [2] of

[2] Turns/in. $= \alpha \sqrt{\text{count}}$.

$\alpha = 4.5$, which is used to determine the skein strength The regularity of the yarn is established by comparison with the ASTM standards, considering separately the neps and the slubs.

A second set of 12 bobbins is spun with a twist $\alpha = 3.80$, and the piece of tubular knit is compared with home made standards for color and trash content appearance. The tubular knitting machine is fed by 10 ends, which gives an extra blending.

We take no account of the ends down during spinning, as it has no meaning whatsoever; 1 end down during a test of 2 hr. on 12 spindles corresponds to 40 ends down/1,000 spindles/hr.

Although we did it in the beginning, we have omitted making single strand yarn strength and the Uster regularity tests, the sampling of these tests being insufficient.

We have realized that our equipment, the card for instance, could deteriorate without our knowing it. Therefore, we have selected one bale, mixed it thoroughly by passing it through hopper blenders, and kept the cotton for reference as standard cotton.

Twice a month, some cotton is taken from that bale and passed through the complete set of tests.

By this procedure, we could detect any sign of deterioration of the testing equipment; in the meantime, it has given us a very good idea of the dispersion of our measures.

Thus, for every 100-bale lot, we are in a position to ascertain the characteristics of the raw, intermediate, and end-use products (Table I).

The fabric color and appearance standards are pieces of tubular knit about 12 × 16 in., graded A to F according to the trash content, ignoring the color. They are framed with a plastic transparent cover. Another set is established according to the color, ignoring the trash.

The test samples are about 25 in. long, and are presented on a plywood board painted in creamy color and also covered by a sheet of transparent plastic. These are compared with the standards and quoted accordingly. Between each two grades there are two intermediate grades, for instance between B and C, one imagines B− and C+.

The evaluation is made by three persons: the chief of the spinning test laboratory, the technical manager, and the managing director. There are generally two who agree on a figure, the third one's judgment differing by no more than one subgrade (⅓ of a grade) from the others.

After judging the trash content, the color is judged the same way.

Some characteristics cannot be measured in laboratory tests, but may be more or less deduced (Table II).

When the complete procedure is accomplished, the results are recorded on the card of the examined lot and a new conclusion is drawn and recorded.

The second conclusion is based mainly on the yarn strength and the fabric appearance (trash content), generally in the same manner as the provisional conclusion.

Sometimes, however, they are quite in opposition, for instance: first qualification: very good, second qualification: very bad.

In this case, the entire test procedure is performed again. (The first procedure leaves about one half of the samples), but the results of the tests have very seldom been found erroneous, so long as the lot is even running.

The claim, if any, is modified according to the spinning tests, one way or other, but when it is aggravated, its acceptance by the shipper is subject only to his good will, the arbitration being made by conventional procedure.

On the other hand, if the spinning test shows that the delivery is above our standards, we pay the shipper a bonus.

We started our pilot plant in January 1952, and it was operated at full capacity in October 1952. We have thus tested all our cotton arrivals of the 1952 to 1957 seasons, totalling about 100,000 bales. This represents 1,600 tests, including duplicated tests, standard cotton tests, and some tests made for special purposes. In a full season, we make four tests a day, but of course, the installation is nearly idle in spring and summer. We use it then for special researches. Some cost figures are shown in Table III.

TABLE II. Deduced Characteristics

Spinning qualities	Ends down can reasonably be deduced from the Micronaire, spinning length, and yarn strength. (The actual ends down during the spinning test bear no signification.)
Weaving qualities	(Loom stops) are influenced by the yarn strength and appearance.
Total spinning waste	Related with the Shirley Analyzer non-lint content—a correlation curve has been established.

How do we employ the data gathered? Some of them, such as the Micronaire, the fiber length, the neps, and the ASTM yarn appearance, need no special attention, so long as they fall within rather wide limits. They are alarm signals that present themselves in very few cases.

On the other hand, the yarn strength and the trash content appearance of the fabric are, by themselves, of paramount importance. These data are entered in the warehouse-book; and the clerk entrusted with the blending should see to it that the blends are made in such a way that the average figures of the strength and appearance of the blends remain practically unchanged for the whole season. This never occurs exactly, considering that the cottons are never available all at once, but, in order to obtain only mild variations, the average is corrected according to the arrivals of raw cotton.

At the moment of passing from one crop to another, the data obtained are of particular importance in facilitating this passage which, if done at random or by traditional methods, could result in extremely prejudicial variations.

Practice has proved the excellence of our method, and our customers greatly appreciate the stability of our yarns' characteristics.

TABLE III. Estimates of Testing Cost

Cost of pilot plant installation	
Spinning test	$26,000.00
1/2 laboratory	$ 4,000.00
	$30,000.00
Depreciation 10%	$ 3,000.00/yr.
Cost of testing	
Depreciation (300 tests/yr.)	$10.00
Operation	$ 5.00
	$15.00

Average weight: 30,000 lb./test = 5 pt./lb.

TABLE IV. Differences Between Two Consecutive Tests

Skein strength		Fabric appearance trash content	
60%	0.2%	70%	⅓ grade or less
28%	3.5%	20%	⅔ grade
12%	+ 5%	5%	1 grade
		5%	1⅓ grade
100%		100%	

How accurate is this method? We can answer this question by considering the results of duplicate tests. The differences between the results of two consecutive tests made on the same samples are recorded in Table IV. One must bear in mind that only the tests the results of which were abnormal or unexpected were duplicated.

If we had duplicated every test, the figures would be much more accurate.

We can assume that the highest variations are to be found in lots that were not even-running and to which the method should not have been applied.

Bearing this in mind, we consider the precision quite sufficient for our purpose.

Spinning Test Results of Five Consecutive Crops, Acala 4-42 Good Middling $1\frac{1}{16}$ in.

As these tests have now been run for five consecutive years and as we have tested about 10,000 bales Acala 4-42 (Mexicali or California) each year it will be of interest to note our experience with the evaluation of these crops. The joint results of these two origins will be considered, as we have never been able to detect any differences *in the end-products* between Acala grown in California or in Mexicali, everything else being equal.

Figure 1 shows the average figure of the yarn strength and fiber appearance of the actual mixes during four consecutive years. This cotton is 100% Acala bought as Good Middling $1\frac{1}{16}$ in.

The yarn strength shows a steady improvement of about 10% in four years' time, which in our opinion is due to the care with which our raw materials were selected.

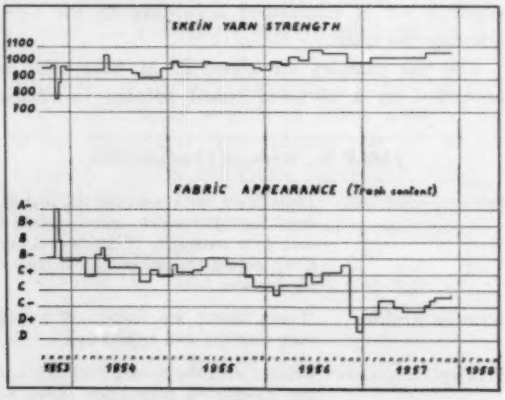

Fig. 1.

If the strength of the yarn has given full satisfaction so far, such is not the case so far as the appearance (trash content) of the fabrics is concerned.

As may be seen in Figure 1, the 1953/54 and 1954/55 seasons are about level (B− to C+).

1955/56 is about 1 subgrade lower (C+ to C), and 1956/57 is at least another subgrade down (C to D+).

It could plausibly be assumed that this is the result of a deterioration of the grade of the cotton, but, such is not the case. In Figure 2, we have compared the classer's grade of each lot with the appearance (trash content) of the fabric for cotton received during the 1953 season and have done the same for the following seasons.

Each diagram does not mean much, as the dispersion is rather wide and the range of grades narrow, but, if we plot (see Figure 3) the averages of the five seasons against each other, we see that the grade of the cotton is better from year to year (except last), the appearance of the fabric is getting worse and worse, and the fabric appearance (trash content):classer's grade correlation for the first four seasons is just the opposite of what it should be, as we found that the better the cotton the worse the fabric. The fifth, the last season, is so catastrophic that it speaks for itself.

Each of these five points represents the average of about 10,000 bales of cotton of the same seed (Acala 4-42) and bought on the same description.

The result is so unexpected that one could question the professional ability of our classer.

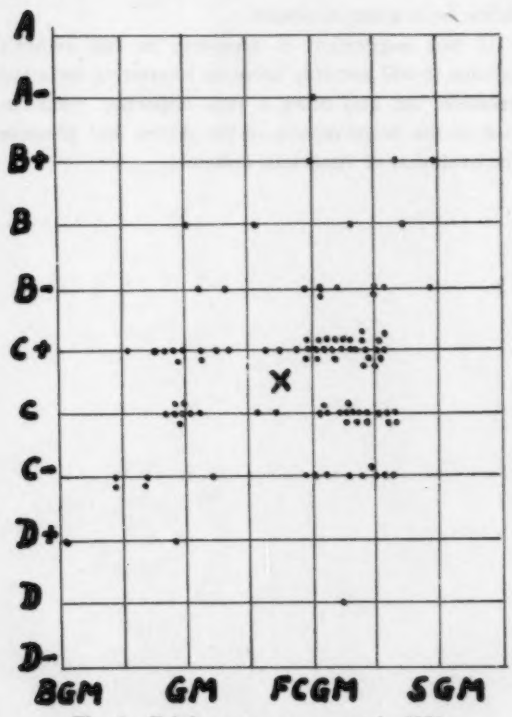

Fig. 2. Fabric appearance vs. grade, 1953.

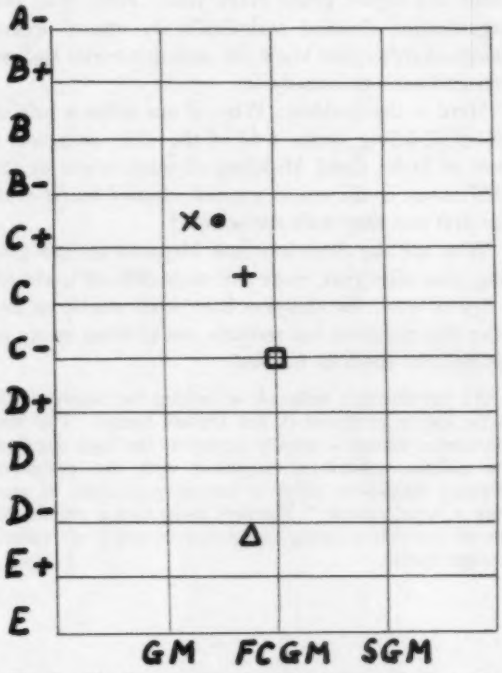

Fig. 3. Yearly averages of fabric appearance vs. grade. ×—1953, ●—1954, +—1955, □—1956, △—1957.

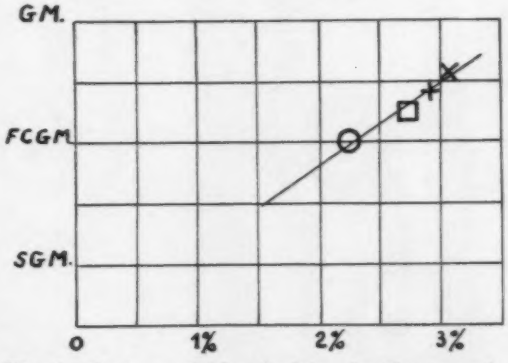

Fig. 4. Grade vs. Shirley Analyzer (nonlint content); yearly averages. ×—1953, +—1954, □—1955, ○—1956.

To make sure, we have compared his idea of the grade with the results of the Shirley Analyzer tests for the average of each season (Figure 4).

The correlation is perfect; the four points, each of which represents the average value of the testing of nearly 10,000 bales, are almost on a straight line.

If we had not tested our cottons by the spinning and weaving test method, we would have wondered why our yarn was getting worse. whereas our cottons were of a higher grade every year. Now, with our organization checked periodically by means of our standard cotton, we know the situation exists and we can endeavor to remedy it.

Here is the problem: Why, if one spins a bale of Good Middling Acala 4-42 of the 1954 crop and a bale of Strict Good Middling of same origin of the 1957 crop, is the result a much cleaner fabric with the first one than with the second?

Why are the American and Mexican cottons getting, year after year, more and more difficult to clean?

Up to now, the shippers have been unable to answer this question, but recently one of them wrote to his Belgian agent as follows:

> We feel that this customer is looking for cotton which is no longer produced in the United States. The fine extraneous matter is usually caused by the high speed of the ginning machinery, together with the extensive cleaning equipment which is necessary in order to produce a "good sample." Farmers insist that a gin should use all possible cleaning equipment in order to remove foreign matter.

In other words, the ginners are now doing a job which was previously left to the spinner, and by so doing they dupe the customer.

We understand very well that, if they did not, they could not compete with those who do. Indeed, why should a farmer accept his cotton ginned into Middling, when he can get a Good Middling next door?

But that does not help the spinner. Are we going to let people play with our cotton, without them even knowing who is going to use it and which is its end-use?

Let us go back to the old days' practice, when ginning was just separating the lint from the seed, and when the responsibility of making good yarn was left entirely to the spinner.

Otherwise, the remedy for the spinner will be to buy his seed-cotton at the farm and have it ginned in his own old-fashioned gin equipment, just the same way it would have been years ago.

Then, when receiving that cotton at his mill, he would know where he stands, and a good look would probably be sufficient to know what kind of yarn and fabric he is going to obtain.

If this suggestion is accepted, in the author's opinion it will not only solve an interesting technical problem, but also bring a very important contribution to the improvement of the cotton and promote the evolution of American cotton.